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Report No. 146

CLIMATIC EXTREMES FOR MILITARY EQUIPMENT

Research and Development Division
Office of The Quartermaster General
November 1951

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Department of the Army

OFFICE OF THE QUARTERMASTER GENERAL

Research and Development Division

Environmental Protection Branch

Report No. 146

CLIMATIC EXTREMES FOR MILITARY EQUIPMENT

By

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Washington, D. C. November 1951

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Climatic Extremes for Military Equipment

SUMMARY

Environmental conditions whose extremes may damage military equipment, or render it inoperative, are defined under seven stresses: thermal, humidity, precipitation, wind, penetration and abrasion, salt spray, and atmospheric pressure. For each of these seven stresses, the probable and practical extremes have been determined from thorough analyses of available information. Conditions are proposed (summarized in tabular form at the end of the report) for the design and evaluation of military equipment intended for use under such extremes.

Operation is characterized under the headings of Ground and Shipboard, with the first being subdivided into World-wide, Arctic Winter, Hot Desert, and Moist Tropics. Applicability of the proposed conditions to each of these types of intended use is indicated. World-wide storage conditions are considered separately.

The conditions as described are intended as a basis for developing laboratory tests to be used in routine evaluation of items, and also for design criteria. Final testing, to validate the design and laboratory tests, should be done at special test sites in areas where the probable extremes are most likely to be approached.

Climatic Extremes for Military Equipment

CONTENTS

Preface

For almost five years, a major activity of the Environmental Protection Branch of the Office of The Quartermaster General has been the study of the extreme environmental conditions which military equipment and personnel are likely to encounter throughout the world. This study, undertaken originally to aid in the proper design and distribution of clothing, was broadened in 1947 to aid in the determination of official temperature limits adopted by the Army (1) for the design, operation and storage of its equipment. Shortly thereafter, Mr. Sissenwine became chairman of a subcommittee of "Unification Group on Environmental Tests" of the Standards Agency, Munitions Board, "to collect the numerical values of environmental extremes on which each Bureau of the Navy or Service of the War Department is basing its natural environmental tests or requiring its equipment to meet in design, tabulate these values, and present this tabulation" along with its recommendations on the best limits.

This report is a direct result of that chairmanship. A preliminary version was circulated, in April 1949, for comment by subcommittee members and other interested specialists. Revision, based on comments received and on additional research, resulted in a final report of the subcommittee to the Unification Group, on 30 April 1951. This was distributed for concurrence to all interested agencies, and forms the basis of standardization action recently initiated by the Munitions Board. In its present form, the report incorporates suggestions and comments made on the second draft, and is distributed as a reference document to those concerned with environmental limitations.

The authors of the report, former heads of the Environmental Physics and Climatology Units of the Environmental Protection Branch, have devoted much of their time, both official and personal, to this study and allied problems. They have often been consulted by representatives of other services on specific problems in this field. This Branch, and its parent Research and Development Division, are honored that Mr. Sissenwine was designated to carry out this important activity for the Department of Defense, and that he and Mr. Court were able to carry this study to the degree of completion indicated by this report.

HOYT LEMONS
Chief, Environmental Research Section

WM. McK. MANTZ, Lt. Col., QMC
Chief, Environmental
Protection Branch

I. INTRODUCTION

1. Environmental Factors

The extremes of environmental conditions which are likely to be encountered by military equipment must be considered in design and in tests to determine acceptability to the armed forces. Equipment may fail during operation, or be permanently damaged while in storage, if exposed to extremes of natural conditions not considered in the original design and acceptance of the equipment. Such failures are not only costly but may destroy completely the effectiveness of a supposedly well-equipped military force.

Environmental limits for the operation of military equipment were set independently by each technical service of the Army and Navy before and during World War II. Consequently, difficulties arose during operations under extreme environmental conditions, when equipment from different sources would not meet the same requirements. For example, Quartermaster items might withstand higher temperatures than Ordnance equipment, but fail at lower rainfall rates. Each of the services tried to remedy these discrepancies by setting some sort of environmental limits for the acceptability of its items. Unfortunately, in many cases the limits were not determined scientifically and consequently they differed. (Tables I and II).

This report evaluates and attempts to state realistically the environmental extremes likely to be encountered by military equipment in modern world-wide warfare. Recommendations are presented in a form suitable for incorporation directly into design criteria, or for use as the basis for the design of acceptability tests.

a. Factors. The factors of the natural environment which affect military equipment are mainly:

(1) Thermal stress, including both ambient air temperature and radiation load.
(2) Moisture content of air.
(3) Precipitation, including snow load.
(4) Wind force.
(5) Blowing sand, dust, and snow (penetration and abrasion).
(6) Salt spray (and other atmospheric contaminants).
(7) Atmospheric pressure.

Other factors of a special or minor nature, not covered at present, include:

(8) Fungus.
(9) Submergence in water.
(10) Rate of change of atmospheric pressure.
(11) Rate of change of temperature and humidity.
(12) Effects of insects.
(13) Green sea load.
(14) Sea surface temperature.
(15) Icing.
(16) Windchill.
(17) Hail.

Although other studies and tests may include such non-natural factors as acceleration, impact, and vibration, such artificial conditions are not considered in this report. The only artificial modification of environment which is considered is that of inclosure, since natural conditions may induce more severe temperatures and humidities with a closed box, tent, or building than in the open.

Any other modifications, however, must be considered as operational conditions. Storage in a ship's hold near the boiler room bulkhead, or operation of a radio set in a steamy laundry room, may encounter conditions more severe than the natural extremes studied in this report. However, such conditions will be most severe at the occurrence of the extreme natural factors. For example, the lubricating oil in a vehicle, although heated by the engine, will run hottest in the desert.

b. Combinations. If factors are to be used realistically, their interdependence and their duration at the time of extremes in nature must be considered. The temperature attained by a military item is an excellent illustration of this approach. The maximum surface and internal temperature attained by any given item out-of-doors are the results of the temperature and motion of the ambient air, the intensity of solar and sky radiation, and the length of time of this exposure. They also depend on the thermal properties of the item, i.e., surface radiative properties, size and shape, thermal conductivity, and specific heat.

Therefore, one set of conditions should be used for inducing the maximum temperature in all items. The temperature actually attained depends on the item under the worst combination of environmental heat loads. This combination involves air temperature and movement, solar radiation, and the maximum duration of those extremes. These conditions form the high end of a Thermal Stress condition. The low end would be similarly determined, but with outgoing radiation normally lost to the Arctic sky replacing incoming solar radiation.

NATURAL ENVIRONMENTAL FACTORS
USED BY THE VARIOUS SERVICES IN SEPTEMBER 1947

FACTOR		FOR OPERATION							FOR STORAGE AND TRANSIT
		GROUND INSTALLATION (OUTDOORS)					SHIPBOARD	AIRBORNE	WORLD-WIDE
		WORLD-WIDE	ARCTIC ONLY	TEMPERATE ONLY	WET TROPICS ONLY	HOT DESERT ONLY	WORLD-WIDE EXPOSED TO WEATHER	WORLD-WIDE UNPROTECTED	UNPROTECTED STORAGE LAND, SEA & AIR TRANSIT
TEMPERATURE (°F)	MAX	130, 160, 122, 120, · 160 130, 135	-65 ? 80	100	104, 113, 110	160, 160, 135	120, 180, (135, 190 IN SUN)	+160	130° F, 160, +170, 160, 160
TEMPERATURE (°F)	MIN	-40, -70, -60, -40, -65 -6T, -65	-50, (-67 TO -94), -65 -65	0	77, 50	30	-35; 29 -35	-65	-40°, -80; -70, -65, -80
RELATIVE HUMIDITY	MAX, WITH CORRESPONDING TEMPERATURE RANGE	(100% AT 68-150) (95% AT 160) (100% AT -65 TO 85°F)	100% AT (-65 TO 60°F)	100% AT 0 TO 75°F	(85% AT ?) 100% AT 50 TO 85°F	(10% AT ?) 95% AT 30 TO 75°F	(ANEESA PROJECT 137) (99% BETWEEN 50° & 95°F)	95±5% AT 160°F	(100% AT 150 TO 68) (85% AT ?) 100% AT 80 TO 85°F
RELATIVE HUMIDITY	MIN, WITH CORRESPONDING TEMPERATURE RANGE	(2% AT 160) (0 TO 5% ABOVE 100°F)	(15% AT 32 TO 80°F)	15% AT 32 TO 100°F	50% AT 90°F 40% AT 110°F	0 TO 5% ABOVE 100°F	(95% AT 77° TO 95°F) (3% AT -35° TO 50°F)	2% OR LESS AT 160°F	(10% AT ?) 0 TO 5% AT 100 TO 160°F
BAROMETRIC PRESSURE (IN. OF Hg.)		25, 17, (29.92 TO 3.44), 4.72, (18.9 TO 31.50)	18.90 TO 30.51	18.90 TO 30.51	23.62 TO 30.51	23.62 TO 31.50	(27 TO 31) (27 TO 32)	29.92 TO 3.44	25, 13, 3.54 TO 31.50
WIND SPEED (KNOTS)		108.3, 108.5, (52 TO 78) 130	30.4, 87	87	130	44	(50 AT -35°F), 90, (150)		108.3, CALM
PRECIPITATION	RAIN (IN./HR.)	(1 TO 3), (6±1), 15, 6	2	4	6	NONE	15	6 ±1	(1 TO 3), NONE
PRECIPITATION	SNOW LOAD (LB./SQ. FT.)	40, 80	80	80	NONE	NONE	1250		NONE
PRECIPITATION	ICE	1/2 IN							1/2 IN
SOLAR RADIATION LOAD (WATTS/SQ. FT.)	TOTAL	(100-140) (115)	(48.5 NORMAL) 80	(90.5 NORMAL) 95	(90.5 NORMAL), 100	115	SALT SPRAY & ULTRA-VIOLET EXPOSURE - BUSHIPS PLAN 9000-S6202-73724	100 - 140	NONE
SOLAR RADIATION LOAD (WATTS/SQ. FT.)	% INFRA-RED (OVER 8000 Å)	40	(50 TO 60) 45	50, 40	50, 40	40			NONE
SOLAR RADIATION LOAD (WATTS/SQ. FT.)	% ULTRA-VIOLET (UNDER 4000 Å)	7	(1 TO 2) 3	4, 5	4, 5	7			NONE
FUNGUS (SPECIES)			MAKE SEPARATE	STUDY					
BLOWING	SAND & DUST (MESH & FT./MIN)	(10 TO 50 MICRONS) (AAF SPEC., 41065)						AAF-SPEC NO 41065	(10 TO 50 MICRONS)
BLOWING	SNOW (SIZE & FT./MIN)							NONE	
SALT SPRAY (SPECIFICATIONS USED)		(QQ-M-151), (QQM-151) (5T-O-2), (TT-P-141 METHOD 606) (GGM-151, 50 HRS.) · (TT-P-141) (BUSHIPS SPEC. PART G OF APPENDIX II) (QQ-M-151 A) (QQ-M-151 A)	QQM-151 A TT-P-141	QQ-M-151 A TT-P-141	QQ-M-151 A TT-P-141		(F.S. QQM-151, APPENDIX II PART A OF N.D. GEN. SPECS.) SALT SPRAY & ULTRA-VIOLET EXP. BUSHIPS PLAN 9000-S6202 -13724) APPENDIX II PART A OF GEN SPECS. QQM-151A-TT-P-141	QQM-151 A	QQM -151, QQM -151, TT-P-141
TOTAL SUBMERGENCE IN WATER (FT. & TIME)		(6 FT. 20 MIN. TO 24 HRS) BUSHIPS SPEC. 16E4					WATERTIGHT AT N.D. SPEC 17-E-11 (15' FOR 30")	DEPENDS ON NATURE OF EQUIPMENT	(6 FT 20 MIN TO 24 HRS.
GREEN SEA LOAD							1000 LBS/FT²		

TABLE I

Similar considerations apply to each of the other factors. For example, in nature, extreme minimum relative humidities occur during the extremes of high temperature, while low temperatures are usually accompanied by high relative humidities.

c. Evaluation. In establishing the environmental limits, it would not be economically sound to use the all-time extremes of the various elements of the natural environment. For example, temperatures at the surface such as -90°F or 136°F, the officially recognized world records, have been recorded only once.

Present military concepts indicate that equipment should be operative at least 90 percent of the worst months, so far as environmental conditions are concerned, in the coldest and in the hottest areas of the globe. This means that in areas of extremes, equipment should be able to operate on all but the three hottest and coldest days per month, respectively. Similar considerations, combined with a great deal of scientific judgment, must be used in evaluating the other factors such as humidity, wind speed, etc.

Such evaluations should be based on frequency distributions of the various elements as well as wide knowledge of the physics of their behavior. Various facts, such as the physical relationship between the maximum attainable dew point (a measure of humidity) and the temperature of the hottest water body, are pertinent in estimating realistic values for the various factors to be used in describing extreme environmental conditions.

2. Types of Conditions

a. Exposure. In establishing environmental stress conditions suitable for the design and basis for acceptability testing of military equipment, the manner in which equipment is exposed to the environment is important. In general, three categories of exposure can be defined.

(1) Active operation, actual use in the intended manner.
(2) Standby for operation, not in use but ready for immediate use.
(3) Storage and shipment, with protective packaging.

For equipment which must or can operate unattended, such as a stationary diesel-engine generating plant, the first category is as severe as any. For equipment requiring human operators, such as vehicles, the limit of operation may be determined by human tolerance -- such as the inability to drive a vehicle in a cloudburst -- and for these the second category is most severe: the vehicle must start again as soon as the storm abates.

Whether standby operation is required under the most extreme conditions depends on the items; consequently, only one set of "operation" extremes is needed, to be applied to each item as required.

NATURAL ENVIRONMENTAL FACTORS RECOMMENDED BY THE VARIOUS SERVICES IN SEPTEMBER 1947

FACTOR			FOR OPERATION							FOR STORAGE AND TRANSIT
			GROUND INSTALLATION (OUTDOORS)					SHIPBOARD	AIRBORNE	WORLD-WIDE
			WORLD-WIDE	ARCTIC ONLY	TEMPERATE ONLY	WET TROPICS ONLY	HOT DESERT ONLY	WORLD-WIDE EXPOSED TO WEATHER	WORLD-WIDE UNPROTECTED	UNPROTECTED STORAGE LAND, SEA & AIR TRANSIT
TEMPERATURE (°F)		MAX	180°F, 185	140	180°F, 140			180	180, 185	180, 185
		MIN	-70°F, -90	-70°, -90	-40°F, -10			-70	-70, -90	-80, -90
RELATIVE HUMIDITY	MAX, WITH CORRESPONDING TEMPERATURE RANGE		100% (100% AT 25° TO 165°)	100%		100% AT 165		100	100 @ 25 TO 158	100, (100 AT -70 TO 180)
	MIN, WITH CORRESPONDING TEMPERATURE RANGE		0% (10% AT -70° TO 180°)	0%			10% AT 180°		0, 102 AT 117	0, (10 AT -70 TO 180)
BAROMETRIC PRESSURE (IN. OF Hg.)			25, (30 TO 20.5)					25	14, (30" TO 1.69")	11, (30 TO 34)
WIND SPEED (KNOTS)			108.3, 120	60		200				100
PRECIPITATION	RAIN (IN./HR.)		10			10				10
	SNOW LOAD (LB./SQ. FT.)									
SOLAR RADIATION LOAD (WATTS/SQ. FT.)	TOTAL		110						125	110
	% INFRA-RED (OVER 8000 Å)		35						44	35
	% ULTRA-VIOLET (UNDER 4000 Å)		2						9	2
FUNGUS (SPECIES)				MAKE SEPARATE	STUDY					JAN-T-152, JAN-C-1731
BLOWING	SAND & DUST (MESH & FT./MIN)		(5 MIC TO 30 MESH AT 2300)							5 MIC TO 30 MESH AT SPEED TO 2300
	SNOW (SIZE & FT./MIN)		(ANY SIZE AT 10,000)							(ANY SIZE AT 10,000)
SALT SPRAY (SPECIFICATIONS USED)			(QQ-M-151 A, AN-QQ-S-191 SALT SPRAY TEST OR NRL)					QQ-M-151 A		QQ-M-151 A
TOTAL SUBMERGENCE IN WATER (FT. & TIME)									(150 FT. 12 HOURS)	(1" FOR 31 MIN BELOW 100°F) (AN-P-13, JAN-P-116)
INSECTS			ALL OPENINGS SCREENED						ALL OPENINGS SCREENED	ALL OPENINGS SCREENED
MAX RATE OF CHANGE OF TEMP. (°F)									1.8 °/SEC.	1.8 °/SEC.
MAX RATE OF CHANGE OF PRESSURE (IN. Hg.)									0.5 IN/SEC.	0.5 IN/SEC.

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TABLE II

The third category, storage and shipment, in general has broader environmental limits than the operation categories. It is vital that equipment, even if inoperative or inoperable because of extreme environmental conditions, should again be operable when those conditions end. Equipment should not suffer permanent damage when exposed to very extreme conditions: it should not crack or distort permanently or be damaged otherwise so as to impair future operation.

Furthermore, while many items will be used only in environments for which they are designed (skis need not operate in deserts, nor diving helmets in extreme cold), the supply problems of global warfare are such that any item may be shipped through, and stored in, any environment. Skis may be stored for months in a warehouse at Daggett, California, and a diving suit may be delayed in shipment in Labrador. Consequently, all items, regardless of intended conditions of use, must be packaged to withstand all extremes of storage conditions.

b. Stresses. From these considerations, and careful analyses of all available climatic and other environmental data from all parts of the world, a set of seven environmental stress conditions has been devised. Items meeting these seven stress conditions should be suitable for their intended military use, provided they otherwise comply with their military requirements. Bases and ramifications of these conditions are discussed in detail in Part II of this report, and are summarized in a table in Part III, Conclusions. The conditions are for the following stresses:

(1) Thermal.
(2) Humidity.
(3) Precipitation.
(4) Wind.
(5) Penetration and Abrasion, by snow, sand, and dust.
(6) Salt spray.
(7) Atmospheric Pressure.

c. Environments. To apply these seven conditions wisely and economically, careful consideration must be given to the intended use of each item. Whether an item is supplied by Army, Navy, or Air Force, it may be operated on the ground, in the air, on the sea, or any combination of these three. However, air operations conditions are the subject of a separate study[5] by the ANC-22 Panel of the Aircraft Committee, Munitions Board, and therefore deleted from this report.

Thus the conditions are varied according to environments of use, considered as:

(1) Operation, Ground, World-wide.
(2) Operation, Ground, Arctic Winter.
(3) Operation, Ground, Moist Tropics.
(4) Operation, Ground, Hot Desert.
(5) Operation, Shipboard, World-wide.
(6) Short-term Storage and Transit, World-wide.

Use of the proper set of conditions for an item will eliminate any possibility of an unrealistic test such as -65°F for an item used only aboard ship, a condition which has never occurred.

Four categories are listed for Operation, Ground, because many items of military equipment for land operation are intended for use in restricted environments, although most must operate anywhere in the world. Such subdivisions are not needed for Operation, Shipboard, since shipboard items may be used on any navigable waters anywhere in the world.

The last category, Short-term Storage (crude storage likely to be encountered in combat theatres) and Transit, likewise has no subdivisions. Any item may be transported through almost any part of the world by land, sea or air and must be able to withstand world-wide extremes, unless special handling is prescribed, as for certain medical supplies.

d. Conditions. The conditions developed in the following sections all tend to simulate nature. Each is defined in terms of a 24-hour period or cycle, or in terms of constant conditions, and in no part are the conditions more severe in any respect than those which might be encountered in some part of the world.

These conditions differ, therefore, from the tests generally used in laboratories to determine acceptability of equipment. A distinction may be made in such tests:

(1) Accelerated tests reproduce natural conditions, but with greater frequency or rapidity than such conditions usually occur.

(2) Aggravated tests involve conditions much more severe than those ever found in nature.

If the conditions proposed in this report are repeated through several cycles, an accelerated test will result, since the natural extremes which the conditions simulate rarely would be expected on successive days. However, since even an accelerated test may require more time than is available for determining the acceptability of equipment, aggravated tests may be necessary. Such tests must always be correlated with the natural conditions, for each type or class of equipment. An aggravated test which has been found to give reliable indications of the suitability of canvas may not be at all suitable for metal items.

Relationship between artificial and natural weather exposure tests on cotton duck samples[3] "was not sufficiently constant to justify reliance on the accelerated technique." Storage stability tests of petroleum products[4] showed "in some instances complete reversal of results obtained at 212°F in comparison with those obtained at 100°F, which

demonstrates the possibility of reaching erroneous conclusions if only the results of accelerated tests were available. (By the definitions given above, these tests would be classed as "aggravated".)

Aggravated tests can be used for determining the acceptance of an item only after extensive correlation with the extremes which occur in nature, as indicated by the cycles presented in this report. They should be used for quality control rather than basic research, which requires testing under natural conditions, possibly accelerated but not aggravated.

II. EXTREME STRESS CONDITIONS

1. Extreme Thermal Stress

Because dissimilar items will not necessarily arrive at the same internal temperatures when exposed to the extremes of thermal stress in nature, no one temperature, air or internal, may be substituted for the combined thermal stress of the natural environment. Factors of air temperatures, air movement, radiation, and duration of the extremes all must be combined in order to make a design criterion or test realistic. Blindly assuming, for example, that all items will reach a temperature of 160°F when exposed in the desert would require cans for rations to have excessive wall thicknesses.

In order that air temperatures throughout the world shall be comparable, they are measured under standard conditions of height, ventilation and radiation shielding. To accomplish this, a shelter for weather instruments has been standardized which supports the temperature-recording device or thermometer at 5 feet or more above the ground. The following discussions of temperature refer to this height, unless otherwise stated.

Sunshine is the only kind of radiation usually considered as a stress on military equipment. It is always a source of heat, and so is considered as a factor of the hot environment. Nocturnal radiation is almost as important; it is the radiation to and through the atmosphere to outer space, and takes place continually out-of-doors under clear skies even during intense sunshine. However, it is mainly important as an aggravant to cold stress and so is considered for the cold environment stress only.

Nocturnal radiation may be simulated in a closed room by controlling the ceiling and upper wall temperatures so that the amount of heat lost by radiation from an object on the floor is the same as it would be in nature. The temperature required for the walls and ceiling is referred to in the discussions that follow as "sky temperature."

a. Hot Environment, Discussion

(1) Operation, Ground, World-wide. In considering world-wide ground operations, the extremes employed should be based on the reasonable premise that troops and equipment may operate in the hottest deserts.

(a) Death Valley, Cal., experiences summers as hot as any place in the world. Its July average of 102°F is approached by records in the Sahara and Iran, but is not exceeded. Data from Death Valley may be considered representative of the hottest extremes.

In Death Valley, the highest recorded temperature is 134°F, only 2 F° less than the generally-quoted world record of 136°F at

Azizia, Tripoli. However, considerable doubt recently has been cast on the validity of either of these records: in no other year in Death Valley has a temperature higher than 127°[c] been observed, and the Azizia reading, made by an expedition, was not corroborated by the observations at any of several nearby stations. A temperature of 140°F on Musandam Peninsula, in the Persian Gulf, cited in one study(5) of design criteria, has not been verified.

Temperatures of 122°F or higher occur on 10 percent of the days in July in Death Valley (Fig. 1). This figure, rounded to 125°F, has been adopted by The Department of the Army(2) as the upper temperature limit for operation. A considerable area of the world (Fig. 2) experiences maximum daily temperatures above 120°F on 3 or more consecutive days per year, on the average.

(b) The duration of the maximum temperature encountered in nature is important. From temperature tabulations for Death Valley, Cal., and Andimishk, Iran, the following durations(6) were found:

Deg. below Max.	:	0	1	2	3	4	5	6	8	10	12	14	16	18
Avg. No. Hours	:	2	3	4	5	6	7	7	9	10	11	12	13	14

Contrary to previous estimates, extremely high temperature is not a momentary occurrence. The temperature may be expected to remain at its daily maximum for 2 hours on the average, and has remained at its maximum for as much as 4 hours, even at 125°F.

The temperature attained by an item exposed to extreme heat also depends upon the base temperature, i.e., the minimum temperature of the morning. The Quartermaster Corps Death Valley Research Group during the summer of 1950 found that extremely hot days usually began with night temperatures generally in the 90's for about 10 hours. Only about 5 hours were required to rise to the maximum, and another 5 hours to fall back to the 90's. On at least 10 days in July, temperatures do not fall below 90°F (Fig. 1). Thus a diurnal temperature cycle of 10 hours at 95°F, rising to 125°F in 5 hours, staying at 125°F for 4 hours, and descending to 90°F in 5 hours appears to be realistic.

(c) Hot environments are due primarily to the intensity of solar radiation, and realistic simulation of a hot environment requires the simulation of its radiation, as to both total intensity and proportionate spectral composition.

Solar radiation intensity in a hot desert is estimated at 105 watts/ft^2 (360 Btu/ft^{2}hr) by Dr. L. B. Aldrich of the Astrophysical Laboratory, Smithsonian Institution. This is about 10 percent higher than the maximum observed by the Death Valley Expedition, but may be observed in the Sahara which is located at lower altitudes. It lies between the values of 123 watts/ft^2, given by Moon(7) for radiation at the top of the atmosphere, and 86 watts, which is normal at sea level when the sun is

AVERAGE FREQUENCY OF DAILY EXTREME TEMPERATURES AT GREENLAND RANCH, DEATH VALLEY, CALIFORNIA IN JULY (1911-1947)

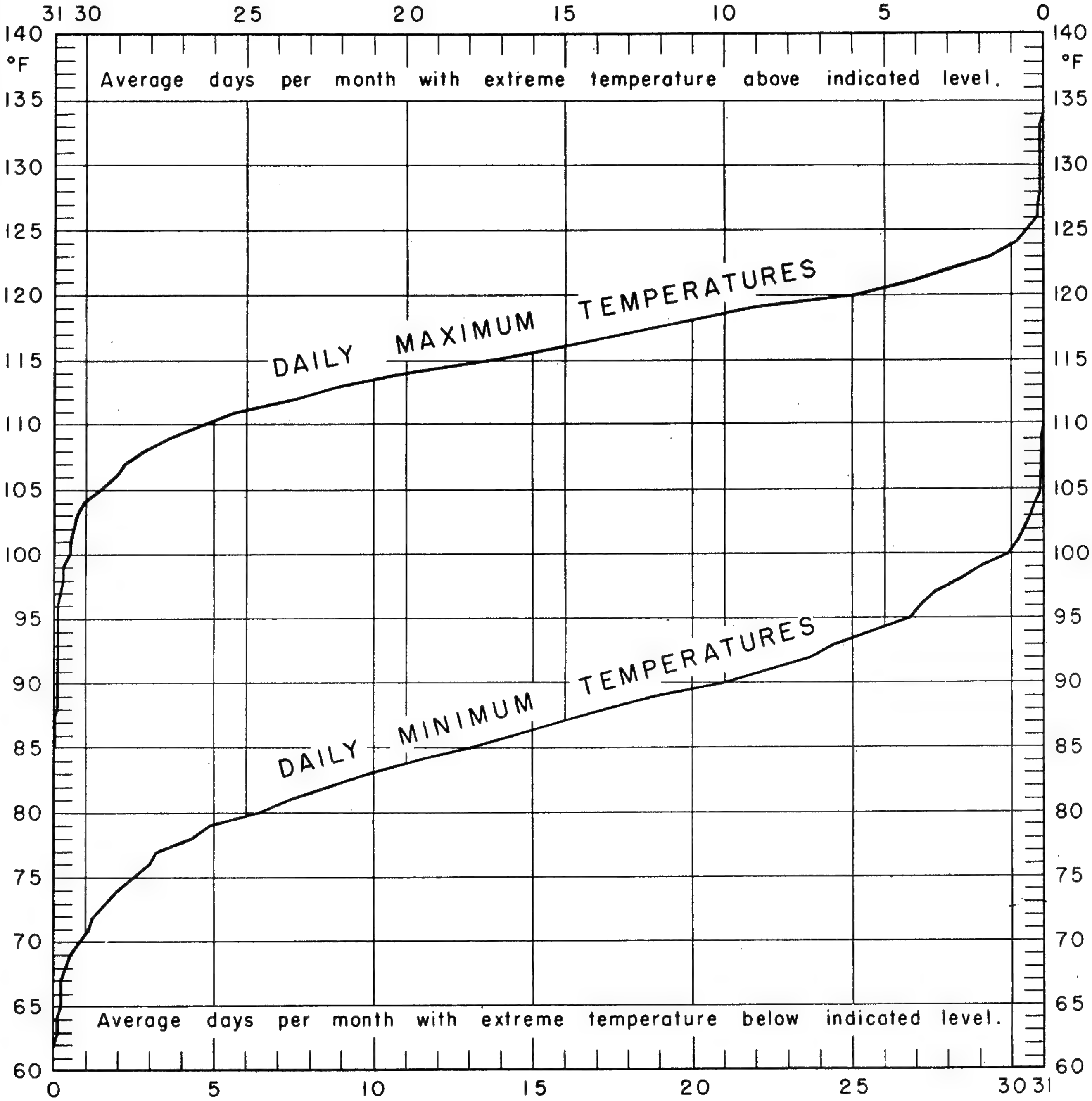

Fig. 1

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directly overhead. An intensity of 111 watts/ft^2 has been measured[5] on the surface of the earth on top of 19,300-ft. Mt. Aunconquila, Chile. At an intensity of 115 watts/ft hr, the spectral composition is estimated[7] at 50 percent infra-red (above 7000 A) and 6 percent ultra-violet (below 4000 A).

The daily cycle of solar radiation in the hot desert is very similar to that of temperature, although the temperature lags behind the sun by a couple of hours. On an absolutely flat horizontal surface, the maximum solar radiation is very transitory. However, for most items there will be little difference between solar load within about two hours of noon. In Death Valley, the total solar radiation on a sphere, as measured on a Hardy-Richard Panradiometer[8] at 1400 to 1500 hours, averaged 89 percent of the noon value. A constant intensity may be assumed for three to four hours surrounding noon, and incorporated into a radiation cycle for a hot desert, where the total duration of sunshine in summer is about 14 hours.

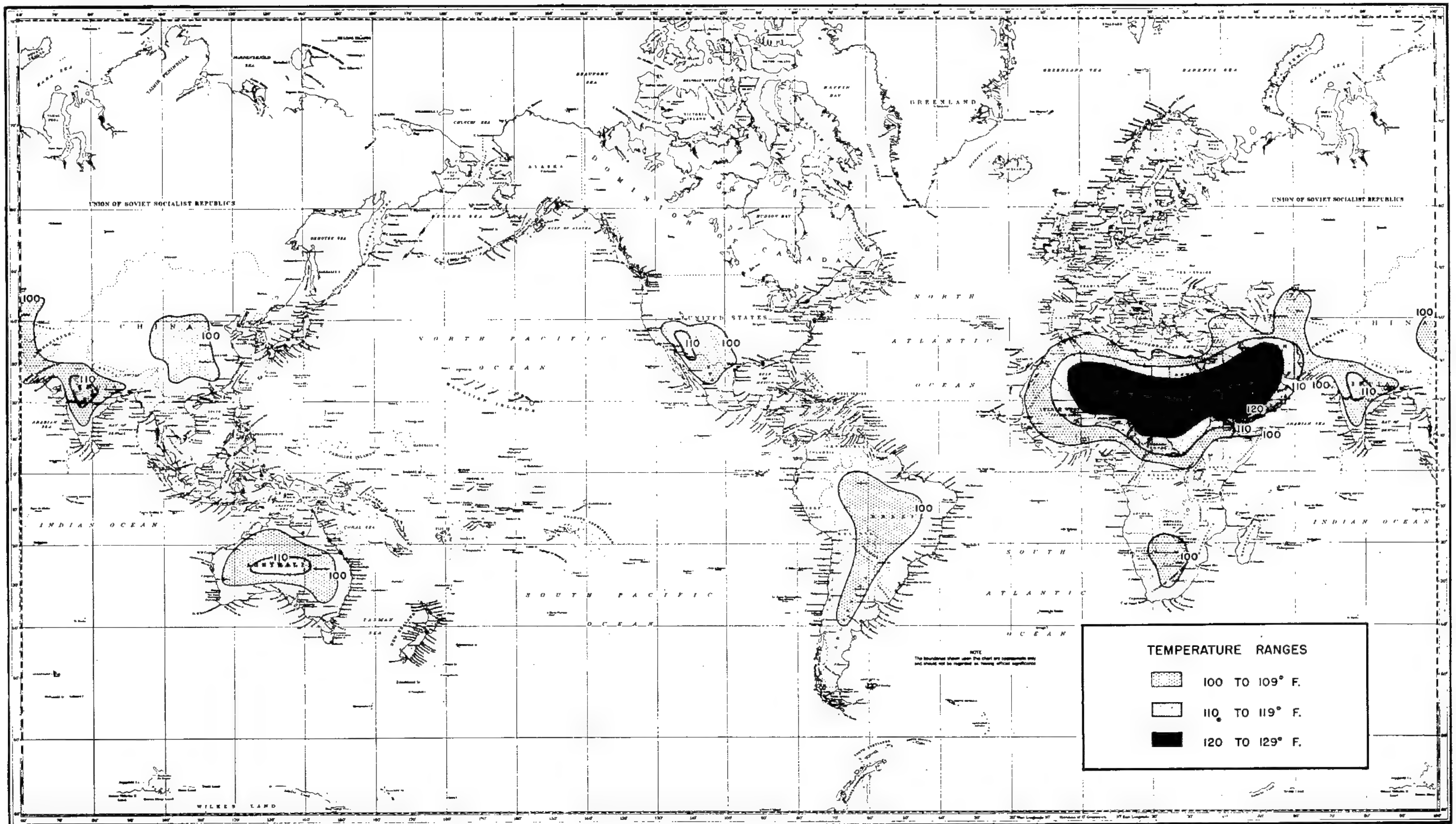
Solar radiation may be assumed to increase in intensity from zero, at the time the temperature rise starts, to a maximum at the time of peak temperature and then to descend to zero with the temperature. Such a cycle will approximate closely desert conditions and probably compensate somewhat for neglecting the geometry involved in the rising and setting of the sun. The total daily heat input on a horizontal surface in such a cycle is within 10 percent of the actual value computed from Death Valley data.

(d) Wind speed is also important in a simulation involving radiation load and varying ambient air temperature: it will lessen the difference between item temperature and air temperature and limit the rise caused by solar radiation of item temperature above air temperature. Wind speed varies considerably with height (Sec. II-4).

From Death Valley data for 1950 and a study[9] made in 1891, winds at 5 to 10 feet average about 8 mph during the hottest hours, are somewhat stronger in the early evening, and average about 5 mph at dawn. The wind speeds in Death Valley appear to be similar to those in other interior desert areas, but may be exceeded somewhat in coastal desert areas, such as along the Persian Gulf. A constant speed of 7 mph at 5 to 10 feet appears to be a fair approximation for use in a cycle.

(2) Operation, Ground, Arctic Winter: The few items of equipment designed exclusively for the cold, snowy Arctic winter will not be required to operate at temperatures much above freezing. Consequently, hot thermal stress is not applicable for operations. Such equipment may be subjected to hot thermal stress in storage; world-wide storage tests will be applicable. Drying of clothing or equipment is an operational problem, not a natural one.

(3) Operation, Ground, Moist Tropics: Equipment designed



AREAS WITH AT LEAST ONE PERIOD OF THREE CONSECUTIVE DAYS PER YEAR WITH MAXIMUM TEMPERATURES IN SPECIFIED RANGES.

Fig. 2

specifically for use in the moist tropics will not experience as high a thermal load as in world-wide use. Records of a number of jungle weather stations[10] indicate that temperatures seldom exceed 95°F. For Balboa Heights, Canal Zone, a typical station at which records have been maintained for 42 years, a frequency tabulation[11] indicates that 94°F will be exceeded on 10 percent of the days in the hottest month. This may be rounded to 95°F.

The duration[12] of temperature near the daily maximum in the moist tropics appears to be the same as in the desert, about 4 hours. The daily minimum for these hot days is about 75°F. A simple cycle analogous to that for world-wide conditions is recommended with a constant temperature of 75°F for 10 hours, followed by a steady rise to 95°F in five hours, followed by 4 hours at 95°F, and then a uniform decline returning to 75°F in ~~4~~ 5 hours.

Solar radiation in the moist tropics is not as strong as in the deserts because of its absorption by water vapor; Moon[7] estimates 90 watts/ft^2 (51% ir and 4.5 uv). Sunshine in the tropics lasts from 11 to 13 hours. For a cycle analogous to that for the world-wide heat stress, the sunshine intensity should increase from zero to 90 watts/ft^2 during the 4 hours preceding maximum temperature, be constant for 4 hours, and then decrease to zero during the next 4 hours.

Wind speeds during the period of maximum temperature are most commonly between 4 and 12 mph at the usual anemometer level. The lower limit, 4 mph, corresponds to wind speed at 5 to 10 ft, and should be used for this cycle.

(4) Operation, Ground, Hot Desert: World-wide extremes apply, since these occur in deserts.

(5) Operation, Shipboard, World-wide: At Bahrein Island in the Persian Gulf, the world's hottest arm of the sea[13], the highest temperature ever recorded is 109°F, and the highest daily maximum average for one month is 98°F. On the coasts of the Persian Gulf the average daily maximum temperature rarely reaches 100° except in the southeast where, at Sharjah, it is 102°F in August. The highest temperature recorded[14] there is 113°F.

A ship under way in the Red Sea has recorded a temperature of 100°F, cited[15] as the maximum air temperature aboard ship. Presumably, this may be exceeded in the Persian Gulf, which, with water temperatures as high as 96°F, is hotter than the Red Sea. It is probable that 100°F will not be exceeded on more than 10 percent of the days of the hottest month, on board any ship in the Persian Gulf.

For Bahrein Island, a cycle may be simulated in the same manner as the previous cycles: 10 hours at lowest temperature,

followed by 5 hours rise to maximum, 4 hours at maximum, and then 5 hours descending. On the basis of the average water surface temperature of 90 to 95°F it seems that the minimum temperature for the cycle should be 90°F. At the weather station on Bahrein Island the average daily minimum is 86°F for the hottest month but even this small land area is cooler than the surrounding water.

Solar radiation on shipboard is about the same as that recommended for the moist tropics, 90 watts/ft^2. A wind speed of 5 knots is recommended, since there is a high frequency[16] of wind speeds of a force less than Beaufort 3 (12 mph) in the Persian Gulf in the summer.

The water body temperature (sea surface) is important in designing certain equipment, such as air conditioners, for operating on board ships at this hot thermal extreme. A temperature of about 95°F is considered likely as indicated above.

(6) <u>Short-term Storage and Transit</u>: The worst conditions of hot thermal stress are encountered enroute to combat areas by items stored under desert sun beneath a tarpaulin, in a closed tent, in a parked airplane, or in a closed boxcar. A maximum temperature of 160°F for four hours, specified by The Department of the Army[2], is in close agreement with the 167°F discussed by the aircraft committee of the Munitions Board[5], with Quartermaster findings[20], and with test cycles[12] in use.

Such very high air temperatures will be found only in closed storage. In a shelter, the inner face of the wall facing the sun will become much hotter, whereas walls in the shade will be cooler. Heat will be transferred to the equipment in storage by conduction from the air and by radiation from the walls. The average inside wall temperature approximates the air temperature.

Thermograph records of air temperature immediately below a tight tarpaulin indicate a 24-hour cycle very similar to that indicated for the previous hot thermal stress tests. Because the air has very little thermal mass, its temperature levels off close to the daily minimum temperature for about 10 hours. It then increases rapidly to 160°F in 5 hours, and after 4 hours at that peak descends to the minimum in 5 more hours. This minimum temperature will be about 90°F, as indicated in studies of Death Valley[21]. Wind speeds encountered inside shelters are negligible.

b. <u>Hot Environment, Recommendations</u>

(1) <u>Operation, Ground, World-wide</u>: A 24-hour cycle of temperature and solar radiation starting with 10 hours at 90°F with no sunshine followed by 5 hours of steady ascending temperature to 125°F, accompanied by sunshine with radiation intensity increasing from 0 to 105 watts/ft^2 (50% ir and 6% uv), constant conditions for 4 hours (at the maximum radiation intensity), finally temperature decreasing to 90°F and sunshine diminishing in intensity to zero in 5 hours. The wind speed at 5 to 10 feet

shall be about 7 mph. Items with small thermal mass may attain maximum stress in only one cycle, whereas those with large mass may require several cycles.

(2) Operation, Ground, Arctic Winter: Not applicable.

(3) Operation, Ground, Moist Tropics: A 24-hour cycle of temperature and solar radiation starting with 10 hours at 75°F followed by 5 hours of steady increase to 95°F, 4 hours at 95°F, and finally decreasing to 75°F in 5 hours. Sunshine (solar radiation intensity) increasing from zero at four hours before maximum temperature is reached to 90 watts/ft^2 (51% ir and 4.5% uv), which is maintained for the duration of maximum temperature and then decrease to zero again in 4 hours. The wind speed at 5 to 10 feet shall be 4 mph. Cycles required are the same as for world-wide.

(4) Operation, Ground, Desert: Same as World-wide.

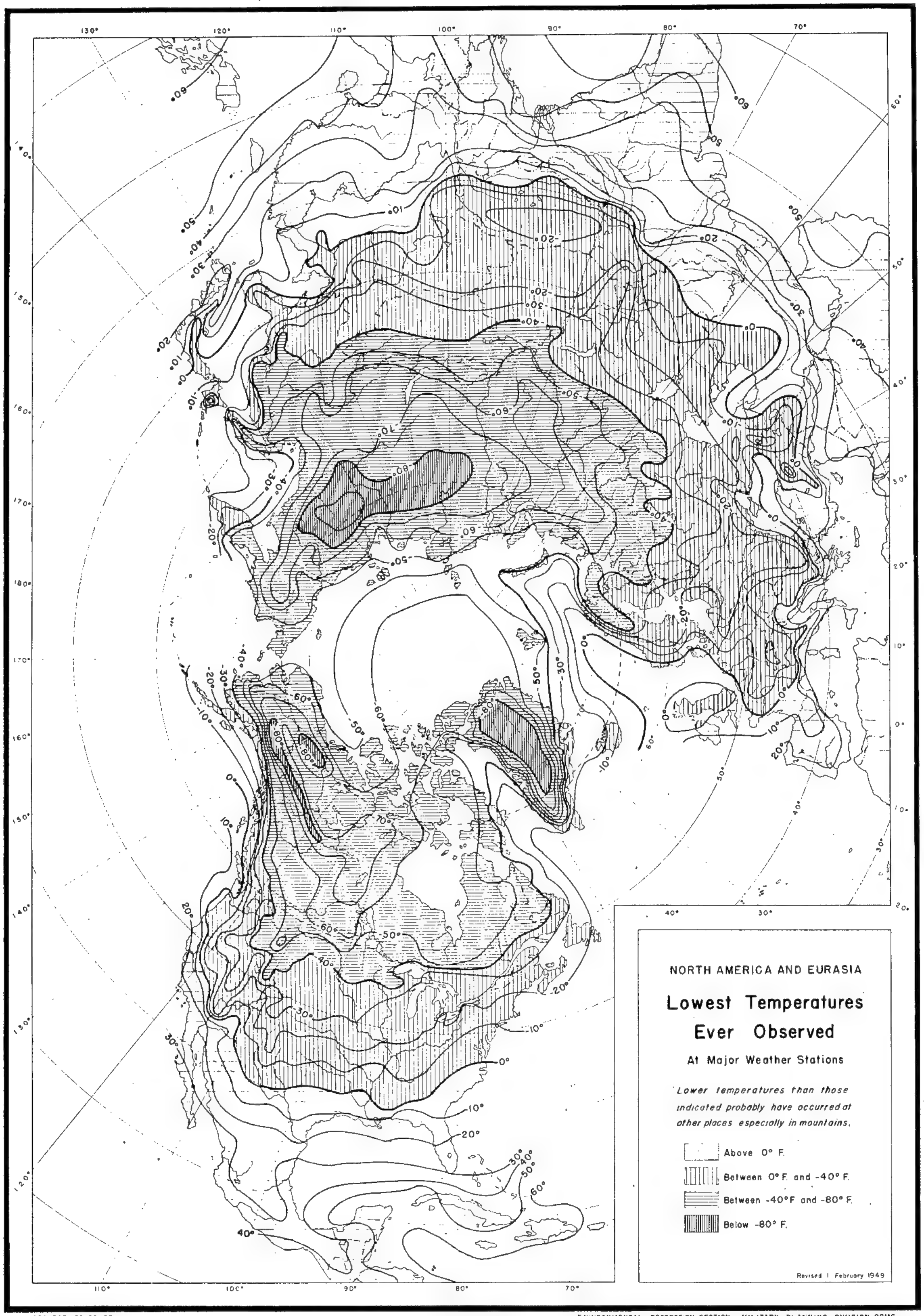
(5) Operation, Shipboard, World-wide: A 24-hour cycle in which 10 hours at 90°F with no sunshine is followed by 5 hours ascending to 100°F, 4 hours at 100°F, and 5 hours descending to 90°F. Sunshine (solar radiation intensity) shall increase from 0 at 4 hours before maximum temperature to 90 watts/ft^2 (51% ir and 4.5% uv), which is maintained during the period of maximum temperature and then uniformly decreased to 0 at 4 hours after the temperature starts to descend. The wind speed at 5 to 10 feet shall be 5 knots. Sea surface temperature is constant at 95°F. Cycles required are the same as for Operations, Ground, World-wide.

(6) Short-term Storage and Transit: A 24-hour cycle in which 10 hours at 90°F is followed by 5 hours ascension to 160°F, 4 hours at 160°F, and 5 hours descent to 90°F. Wall temperatures need not be controlled; it is assumed that they will be fairly close to air temperature. Wind speed shall be negligible.

c. Cold Environment, Discussion

(1) Operation, Ground, World-wide: Temperatures colder than -65°F have been observed[22] over a large area of the northern hemisphere (Fig. 3); in approximately the same area temperatures do not go lower than -40°F on more than 10 percent of the days in the coldest month of the year (Fig. 4).

At Verkhoyansk, Siberia, where the world's lowest surface temperature (-90°F) was recorded, winter temperatures[23] are most frequently between -60 and -65°F; such temperatures occurred on 327 out of 2522 thrice-daily observations in the three winter months during a 10-year period. Twice -83°F was observed. Records of a 1-year expedition on the Greenland icecap show 11 separate periods[24] when the temperature was below -76°F, the longest for 24 hours, and 55 various periods at -58°F or lower, including one of almost four days. Thus -65°F seems a justified



PROJECT 83-02-07
M-7025

ENVIRONMENTAL PROTECTION SECTION, MILITARY PLANNING DIVISION, OQMG

Fig. 3

lower temperature limit, as specified by the Army[2], and the duration of 3 days is also logical.

A simulated sky temperature of -80°F with air temperature of -65°F is recommended in a report[25] on Quartermaster weather simulation chambers. Most places expecting temperatures of -65°F on 10 percent of the coldest days in the month have average temperatures around -40°F; items with large thermal mass will assume this temperature, which therefore is recommended for equilibrium. Verkhoyansk has an average January temperature of -58°F.

(2) Operation, Ground, Arctic, Winter: Same as World-wide.

(3) Operation, Ground, Moist Tropics: Not applicable.

(4) Operation, Ground, Hot Desert: Not applicable.

(5) Operation, Shipboard, World-wide: Comparison of charts of minimum temperature[22] with charts of Arctic and sub-Arctic navigable waters[26] indicates that any arm of the sea which even very rarely experiences temperatures lower than -20°F would be frozen too solid for navigation. The lowest temperature[26] ever encountered by a ship under way was -40°F, near the northern coast of Alaska on a steamship beset on Sea Home Reef. Recent U. S. Navy design criteria[27] for use in Arctic and cold weather areas also specify -20°F as the minimum temperature requirement. The late Col. Charles J. Hubbard, Arctic expert of the U. S. Weather Bureau, agreed that -20°F is a practical minimum temperature for vessels under way, but advocated -65°F so that vessels could be frozen in as stationary outposts in polar waters during winter.

A simulated sky temperature of -45°F is recommended, on the basis of a weather simulating chamber study.[25] Ship motion and the strong offshore winds necessary to carry sub-zero air over the open water will create a wind speed of about 40 knots, corroborated by the recent naval design criteria.[27] A duration of 24 hours is considered the limit of a weather situation causing exceptionally cold offshore winds.

(6) Short-term Storage and Transit: A limit of -80°F for storage is directed by The Department of the Army[2] because North America and Asia, and also Greenland, have experienced[22] colder temperatures: -81°, -90°, and -85°F, respectively (Fig. 3). Should such temperatures occur at some military encampment, combat equipment must recover its ability to perform when temperatures return to the operating range. Extreme cold temperatures at the earth's surface occur usually during calms. The duration is set at 24 hours; temperatures on the Greenland icecap[24] were continuously -76°F or lower for 24 hours on one occasion, for 19 hours on another, and for shorter periods in the nine other occurrences during one winter.

Areas which may experience -80°F have mean monthly temperatures around -40°F. This average temperature usually will be assumed by

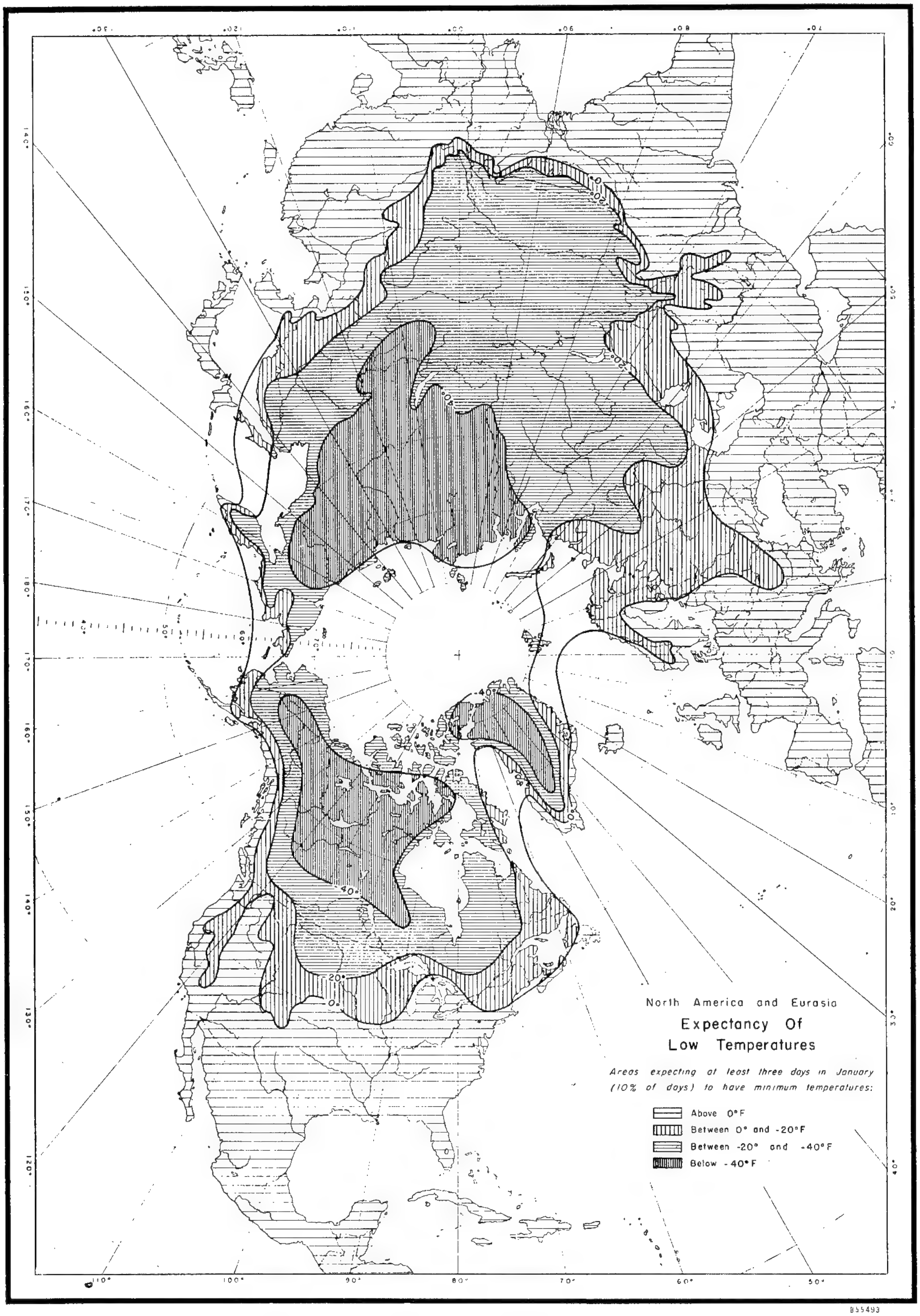

North America and Eurasia
Expectancy Of
Low Temperatures
Areas expecting at least three days in January (10% of days) to have minimum temperatures:
Above 0°F
Between 0° and -20°F
Between -20° and -40°F
Below -40°F
0°
-20°
-40°
110°
100°
90°
80°
70°
60°
50°
140°
150°
160°
170°
180°
10°
20°
30°
40°
B55493

Fig. 4

objects exposed in the open, with some fluctuation corresponding to the daily temperature.

For items subjected to unheated air transport, a free air temperature of -80°F is applicable. The probable minimum temperature to be expected up to 32 km (about 100,000 feet) is given by Warfield[19] as -135°F. The coldest temperature[17,18] ever recorded by upper air soundings up to 16 km (52,500 feet) over North and Central America and adjacent island is -125°F, over San Juan, P. R. at 16 km. Recently proposed aircraft criteria[5] cite a minimum of -139°F at 62,300 feet. However, the Air Materiel Command's Committee for Testing Dangerous Materials for Transportation by Air has indicated that exposure above 25,000 feet is unlikely. Ratner[18] gives -63°C (-81°F) as the coldest temperature observed over North and Central America up to 8 km (about 26,000 feet).

d. Cold Environment, Recommendations

(1) Operation, Ground, World-wide: Ambient air, -65°F; simulated sky temperature, -89°F; wind, calm; duration, 72 hours; preceded by equilibrium at -40°F.

(2) Operation, Ground, Arctic Winter: Same as World-wide.

(3) Operation, Ground, Moist Tropics: Not applicable.

(4) Operation, Ground, Hot Desert: Not applicable.

(5) Operation, Shipboard, World-wide: Ambient air, -20°F; simulated sky temperature, -45°F; air speed, 40 knots; duration, 24 hours.

(6) Short-term Storage and Transit: Ambient air, -80°F; wind, calm; duration, 24 hours; preceded by equilibrium at -40°F.

2. Extreme Humidity Stress

Humidity, "the state of the atmosphere with respect to water vapor content,"[28] may be indicated in several different ways, either by the amount of water vapor physically present or by the relation of the water vapor content to the air temperature.

a. Definitions

The amount of vapor present may be indicated[28] in one of the following seven ways:

(1) Absolute Humidity:

(a) The mass of water vapor present per unit volume of space, i.e., the density of water vapor; usually expressed in grams per cubic meter or grains per cubic foot. This quantity decreases with adiabatic expansion and increases with adiabatic compression.

(b) The gas pressure exerted by the water vapor per unit area, expressed in barometric units. These two definitions are equivalent, since, at any given temperature, vapor pressure varies directly as vapor density.

(c) The term is sometimes applied by heating engineers to the number of grains of moisture per pound of moist air. This usage corresponds to the meteorological definition of specific humidity.

(2) Specific Humidity:

(a) The mass of water vapor in a unit mass of moist air, usually expressed as in grams per gram or per kilogram of moist air. Specific humidity must be distinguished from mixing ratio.

(3) Mixing Ratio:

(a) The mass of water vapor per unit mass of perfectly dry air in a humid mixture.

(4) Vapor Pressure:

(a) The pressure of the vapor of a liquid in confinement so that the vapor can accumulate above it.

(b) The partial pressure of the water vapor in the atmosphere. The units used to express vapor pressure are the same as those for the total air pressure.

(c) "Vapor tension" was formerly widely used for this term but it no longer is in common use.

(5) Dew Point:

(a) The temperature to which air must be cooled, at constant pressure and constant water vapor content, in order for saturation to occur. Since the pressure of the water vapor content of the air then becomes the saturation pressure, the dew point may also be defined as the temperature at which the saturation pressure is the same as the existing vapor pressure.

(6) Wet-bulb Temperature:

(a) The lowest temperature to which air can be cooled by evaporating water into it at constant pressure, when heat required for evaporation is supplied by the cooling of the air. This temperature is given by a well-ventilated wet-bulb thermometer.

(7) Relative Humidity:

(a) The ratio of the amount of moisture in a given volume

of space to the amount which that volume would contain in a state of saturation.

(b) The ratio of the actual vapor pressure to the saturation vapor pressure.

Both the amount of water vapor present and the amount in relation to air temperature are important in the design and testing of military equipment. They both affect the operation of many pieces of equipment, while the latter must be considered in problems of storage such as corrosion, fungus growth, and general deterioration. Consequently, final recommendations use <u>relative humidity</u> for storage extremes. In many instances, dew points are used in arriving at the extreme absolute humidity, because dew point temperature can more easily be correlated with the surface temperature of the water body from which the moisture comes. Relationship of the various units by which absolute humidity may be expressed are given in Fig. 5.

b. <u>Absolute Humidity, Discussion</u>

Absolute humidity governs such things as the effectiveness of a heated clothes drier and the efficiency of the cooling tower of a power plant using evaporative cooling. It is the governing factor in human comfort above about 70°F, and it also may affect the ease of laying down a smoke screen.

SCALES FOR COMPARING VALUES

OF ABSOLUTE HUMIDITY, DEW POINT AND VAPOR PRESSURE

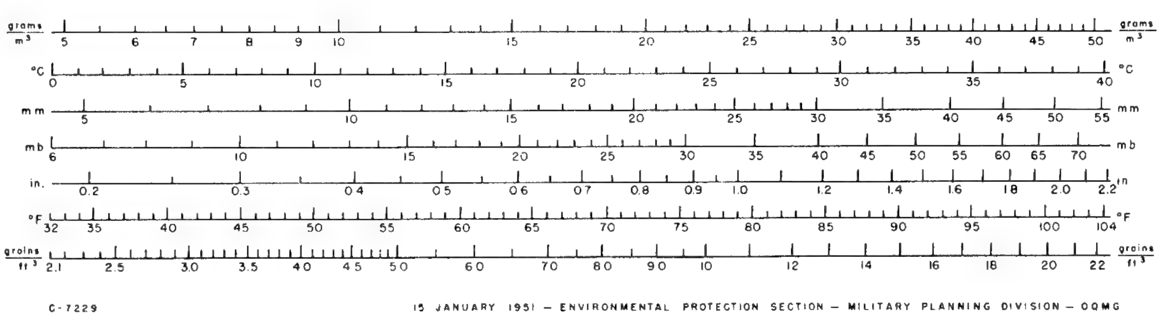


FIGURE 5

It is also important when an item is subjected to a sudden change in temperature: bringing a camera from the cold outdoors into a heated room where the absolute humidity is higher causes internal condensation, whereas taking it out into subfreezing temperatures from a moist heated room causes internal frost which may prevent shutter action. Countering these hazards is a problem in technique rather than in design.

Pertinent facts on absolute humidity may be more easily discussed according to the operational subdivisions.

(1) Operation, Ground, World-wide: The highest possible absolute humidity is directly dependent upon temperature; it doubles for about each 18 F° temperature rise. Theoretically, therefore, the world extremes of absolute humidity should occur in the coldest polar and hottest desert air. These theoretical assumptions are valid for the cold extreme, but the atmosphere generally does not contain all the moisture possible at high temperature extremes. The amount is limited by the temperature of the source of this moisture, that is, the surface temperature of the water body from which the water evaporates.

Dew points above 90°F (corresponding absolute humidity is 14.951 grains per cubic foot), the surface temperature of our hottest arm of the sea, the Persian Gulf, are extremely unlikely.[29] Consequently, the humidity tests, Group 30 in Air Force Specifications No. 41065, far exceed extremes in nature. They include temperatures of 160°F with relative humidities of 95% ± 5%, or dew points of 156 to 160°F, which can come only from a natural water source having a surface temperature of about 160°F. These tests can be used advantageously as an aggravated test, after correlation of consequent deterioration with that encountered during extremes reached in nature.

(2) Operation, Ground, Arctic Winter: At extremely low temperatures, the absolute humidity is generally the maximum possible at those temperatures, but quantitatively is a minimum. It is the maximum possible because extremely low temperatures are attained only after air is cooled far below its original saturation temperature. Much vapor is condensed or sublimed and the resultant cooled air left saturated. The absolute humidity corresponding to saturation at the -65°F minimum operating temperature is 0.0102 grains per cubic foot.

(3) Operation, Ground, Moist Tropics: Jungles cover a very great percentage of the areas considered as moist tropics. In these areas, typified by the lowlands of India, the tropical Pacific Islands, and the Amazon and Congo basins, dew points range from 75 to 85°F, depending mostly on the temperature of and distance from the body of water from which the prevailing winds, the trades or monsoons, blow. For example, the highest dew points[35] observed at each of 24 stations in India over a five-year period from July, 1944, through June, 1949, were:

Dew Point:	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87
No. cases:	1	-	-	1	2	-	-	1	-	-	-	-	-	2	4	5	1	1	3	3

Of all territory under control of the United States, comparable dew points are observed most frequently in the Panama Canal Zone; studies cited later in the relative humidity discussion, show that such dew points are quite common there. As discussed in the next paragraph, coastal regions of extremely hot deserts, although receiving very little precipitation, are areas of the highest air moisture content. In fact, the maximum dew point of which authentic record has been found is 88°F, observed at Sharjah, Trucial Oman, on the Persian Gulf. Because such areas are so limited and because these extremes are very transitory, the absolute humidity corresponding to the slightly lower jungle maximum dew point of 85°F is considered realistic as a basis for a test and a design limitation.

(4) Operation, Ground, Hot Desert: The extreme values of absolute humidity in hot deserts are not well defined, and must be chosen rather arbitrarily. Dew points are generally about 30 to 40°F during the hottest months with a corresponding absolute humidity of about 2 grains per cubic foot. Such conditions are illustrated by Reggan, Algeria (in the Sahara Desert), where the average maximum temperature in July is 114°F and the average relative humidity at the time of maximum temperature is only about 7 or 8 percent, indicating a dew point in the thirties. However, coastal regions of desert areas, such as the shores of the Persian Gulf and Gulf of California, do have extremely high absolute humidities in the lower air layers, especially when sea breezes are blowing, because the coastal waters are very hot. Thus the top desert extreme is the same as for the moist tropics.

(5) Operation, Shipboard, World-wide: Since all atmospheric moisture comes originally from the oceans, absolute humidity on shipboard is generally higher than that over the land. Consequently, the highest absolute humidity to be expected on shipboard is at least as high as that for Operation, Ground, World-wide. The minimum absolute humidity depends on the lower temperature limit that is used for shipboard operation, -20°F. Since it is not likely that the air at this temperature will be much below saturation, the dry extreme for shipboard operations should be 0.17 grains per cubic foot, corresponding to saturation at -20°F.

(6) Short-term Storage and Transit: Absolute humidity is not as important in deterioration under storage conditions as is relative humidity.

c. Relative Humidity, Discussion

The chief effect of relative humidity is on degradation. It also affects the operation of many electronic devices, Ordnance items, etc. At

high relative humidities many organic materials swell and/or are attacked by micro-organisms when temperatures are within certain ranges. Fungi develop most actively at temperatures well above 40°F with relative humidities greater than 40 percent; at the lower limit of either temperature or humidity, the other factor must be high to permit active growth, i.e., 40°F and 80 percent or higher, 80°F and 40 percent or higher.

Corrosion on metals and etching on ceramic materials is negligible at relative humidities of less than 30 percent.(30) Low relative humidities are detrimental to certain organic materials, which dry and split; their effect on metals and ceramic products is beneficial as corrosion and etching are reduced. Static electricity may become a problem at extremely low relative humidities.

Condensation appears to play an important part in the corrosion of metals and the breakdown of electronic equipment in the moist tropics. In a recent specification(31) designed for testing against high humidity, the temperature is varied ± 5 C° (9 F°) from any temperature between 22.0° and 28.0°C (71.6° and 82.0°F) at least once each hour. The rate of temperature change is optional, consistent with maintenance of the maximum temperature not in excess of 20 minutes out of each hour. The relative humidity shall be not less than 95 percent. At least once each hour the relative humidity is to be 100 percent, with the duration optional, and not necessarily coinciding with the maximum temperature phase. Total exposure time is given as 30 days unless otherwise specified.

Although the limits of temperature and humidity of this cycle are realistic, it serves best as an aggravated test and should be used only after proper correlation with a natural cycle. In the moist tropics a range of 5 C° (9 F°) roughly covers the extremes for the day and is not attained hourly; temperature changes are slow and slight. The lowest temperature usually is associated with the highest relative humidity, the highest temperature with the lowest relative humidity. Rapid changes as proposed will not penetrate to the same depth in an item of equipment as the slower natural changes, so the resultant degradation may therefore be different.

Any time limit for duration of extreme humidity is highly arbitrary: the conditions may persist for the major part of a year. A 30-day limit may be chosen, not as a basis for judging long-term degradation, but to give the item which is to be operated in these moist conditions enough time to reach equilibrium.

Relative humidity can vary from a maximum of 100 percent (in the Arctic and in the jungles) to almost 0 percent (in the hottest deserts). The air also may be very dry at low temperatures, especially in mountainous areas, and even in lowlands subject to downslope winds (Foehn or Chinook). However, temperatures are very important in the rate of

degradation as are cycles, condensation, and duration of these conditions. The worst combination of these likely to be found in nature must be specified for design and testing.

Degradation due to extremes of humidity is important at the highest temperature at which these extremes exist. Thus for the moist extreme the worst conditions are those found in the tropical jungles. Three different studies[32,33,34] of jungle conditions in the Canal Zone show dew points always between 75 and 84°F and air temperature seldom exceeding these by more than a few degrees because of this high moisture content, the shade, and the cloudiness. Although the relative humidity in the jungle dropped to a minimum of about 70 percent on a number of occasions, it stayed there for such short periods of time that the average monthly humidity in the jungle was above 95 percent. The daily cycle included temperature variations of only a few degrees and a few hours, usually near dawn, when the humidity was 95 to 100 percent.

At the dry extreme, the desert dew points of 30 to 40°F combined with the 125°F air temperature required for operations or the 160°F found in closed tents, parked aircraft, etc., cause a great amount of drying out and cracking. Even lower dew points exist over sand dune areas. The QM 1950 Death Valley Group noted an 8°F dew point at 110°F for a 2 percent relative humidity. However, the relative humidity in an Arctic warehouse heated to 50°F with an ambient dew point of -50°F is only 1/4 of this, if the absolute humidity in the warehouse remains the same as that outside. Besides, it is constant for weeks and months in contrast to the few hours a day in the desert. However, it is still uncertain whether a piece of leather or wood will deteriorate faster in the Arctic dryness than in the cyclic desert dry heat. Consequently, a cyclic set of conditions simulating the desert, and constant temperature and humidity long-period conditions, are both recommended for the dry storage extreme.

d. Wet Extreme, Recommendations

(1) Operation, Ground, World-wide:

(a) An absolute humidity of 13 grains per cubic foot corresponding to a dew point of 85°F.

(b) Daily cycles of 95 ± 2% RH at 80° to 85°F for 20 hours, followed by 4 hours of 100% RH with condensation at 75 to 80°F. (Air movement and radiation negligible.)

(2) Operation, Ground, Arctic Winter:

(a) An absolute humidity of 2.1 grains per cubic foot corresponding to saturation at 32°F.

(b) RH of 98 to 100% at all temperatures below freezing.

(3) Operation, Ground, Moist Tropics:

(a) Same as Operation, Ground, World-wide.
(b) Same as Operation, Ground, World-wide.

(4) Operation, Ground, Hot Desert:

(a) Same as Operation, Ground, World-wide.
(b) High RH cycle not applicable.

(5) Operation, Shipboard, World-wide:

Same as Operation, Ground, World-wide.

(6) Short-term Storage and Transit:

(a) Absolute humidity condition not applicable.
(b) Same as Operation, Ground, World-wide.

e. Dry Extreme, Recommendations

(1) Operation, Ground, World-wide:

(a) An absolute humidity of 0.01 grains per cubic foot, corresponding to saturation at -65°F.

(b) RH of 5% at a temperature of 125°F for four hours, preceded by ten hours of 15% at 90°F (in conjunction with the Hot Thermal Stress Test).

(2) Operation, Ground, Arctic Winter:

(a) Same as Operation, Ground, World-wide.
(b) Low RH conditions not applicable for outdoor operations.

(3) Operation, Ground, Moist Tropics:

Not applicable

(4) Operation, Ground, Hot Desert:

(a) An absolute humidity of 0.5 grains per cubic foot, corresponding to a dew point of about 0°F.

(b) Same as Operation, Ground, World-wide.

(5) Operation, Shipboard, World-wide:

(a) An absolute humidity of 0.17 grains per cubic foot, corresponding to saturation at -20°F.

(b) Low RH conditions not applicable.

(6) Short-term Storage and Transit:

(a) A relative humidity of 2% at a temperature of 160°F for four hours, preceded by ten hours of 15% at 90°F, in conjunction with the Hot Thermal Stress Cycle.

(b) A supplementary or substitute test of 30 days at 50°F and 1/2% relative humidity, simulating heated Arctic storage, is also recommended.

3. Extreme Precipitation Stress

Precipitation, the meteorological term for water of any form falling on the earth from clouds, may be either liquid (rain or drizzle) or frozen (snow, hail or sleet). Liquid precipitation affects the operation of machinery, especially engines, and of men, so that they must be protected against it by waterproof clothing and shelters. It also may cause floods.

Snow is the only form of frozen precipitation discussed here, in the second part of this section. Hail, while possibly very severe, is so sporadic and localized that designing against the worst possible hailstorm is uneconomical. Freezing rain imposes a definite environmental stress which depends on the exact character of the item affected, primarily wiring and small structures; for such equipment, special studies are required, such as those made by power and telephone companies.

a. Rainfall, Discussion

Although the world's record[36] for the greatest yearly average rainfall is held by Cherrapunji, India, with 426 inches, and the greatest amount in a single year may have occurred in the Philippines or in Hawaii (authorities differ), studies of record rainfalls of the world and for the United States[37,38,39] indicate that the maximum rates of rainfall occur in thunderstorms, with those of the United States being as intense as any in the world. Temperatures during such rains are around 70°F.

(1) Intensity. From the maps in a detailed study[40] of excessive rainfall in the United States, Table III has been prepared to show the maximum rainfall to be expected over the western half of the United States in a given number of years, for various durations. Expectations along the Gulf coast are about twice as heavy as those cited in Table III, with 5-minute falls exceeding 0.55 inches expected once in 2 years, 1-hour falls of 3.00 inches expected once in 5 years, of 5.00 inches once in 100 years, etc.

TABLE III: MAXIMUM RAINFALL (INCHES) TO BE EXPECTED AT VARIOUS PERIODS FOR DIFFERENT INTERVALS OVER THE WESTERN HALF OF THE UNITED STATES

	Minutes				Hours					
Once in:	5	10	15	30	1	2	4	8	16	24
2 yrs.	.35	.60	.75	1.00	1.25	1.50	----	----	----	----
5 yrs.	.45	.75	.90	1.30	1.50	1.90	2.25	2.75	2.85	2.95
10 yrs.	.50	.80	1.10	1.60	1.75	2.25	2.65	3.00	3.25	3.50
25 yrs.	.55	.90	1.25	1.80	2.20	2.50	3.00	3.50	3.85	4.00
50 yrs.	.60	1.00	1.40	2.00	2.50	3.00	3.50	4.00	4.15	4.50
100 yrs.	.65	1.10	1.55	2.20	2.80	3.50	4.00	4.50	4.75	5.00

These figures show that the rate of rainfall decreases as the duration increases. Analysis[41] of "millions of point-rainfall observations which have been recorded around the world," shows that the maximum amount of rain which can accumulate at a point during a single storm increases with the square root of the duration,

$$R = 14.3 \sqrt{D},$$

where R is the maximum possible rainfall accumulation in inches in a given storm and D the rainfall duration in hours. All the world records of extreme rainfall intensity fit this formula closely, but the expectations of such rainfall amounts is rather slight. The maximum amounts estimated[40] to occur along the Gulf Coast of the United States once in 100 years are only about one-fourth of these absolute maximums (Table IV).

If the 150 inches which once fell at Cherrapunji in five consecutive days fell at a uniform rate, the fall was only 1.25 inches per hour, but recomputing the constant in the above formula shows the heaviest 1-hour rain during this period could have been 13.7 inches, approximately the maximum for that duration. On the other hand, over a 42-year period, the heaviest 1-hour rainfall at any of nine panama Canal Zone Stations[42] was 5.68 inches at Gatun (average annual rainfall: 125 inches), and the heaviest 5-minute fall was 0.90 inches at Balboa (average annual rainfall: 70 inches), slightly less than that expected every 100 years on the Gulf Coast. By the above formula, a rain yielding 0.90 inches in 5 minutes would give only 3.1 inches in an hour. Evidently, although it may rain more often in the tropics, it does not rain much, if any harder, than in temperate latitudes under the influence of maritime tropical air.

TABLE IV: RATIO OF THEORETICAL WORLD MAXIMUM RAINFALL (BY FORMULA) TO 100-YEAR EXPECTED MAXIMUM ALONG THE GULF COAST FROM DATA

	Minutes				Hours					
Duration:	5	10	15	30	1	2	4	8	16	24
Gulf, 100 yrs:	1.00	1.50	2.00	3.25	4.50	6.50	8.00	9.50	11.00	14.00
World Maximum:	4.13	5.84	7.15	10.11	14.30	20.22	28.60	40.33	57.20	70.00
Ratio:	4.1	3.9	3.6	3.1	3.2	2.4	3.5	4.2	5.2	5.0

Because the intensity of rainfall decreases with its duration, it is necessary that any test of the ability of military equipment to withstand precipitation be based on a <u>variable</u> rate of fall. It would be most unrealistic to continue a test at 14 inches per hour for 12 hours since for that period the total fall in the most severe natural rainstorm would be 49.5 inches.

Military equipment must withstand both prolonged soaking rain and brief downpours. Consequently, a realistic set of conditions for precipitation must involve both types of rainfall, with the rates chosen to approximate those likely to be encountered. Based on the relation between expected Gulf Coast rainfall and the formula derived from one-time extremes throughout the world (Table IV), it seems that there is little likelihood of failure of any equipment which can withstand rainfall of half the maximum possible intensity.

(2) <u>Drop Size</u>. Both the size and speed of fall of natural raindrops must be approximated closely in any test to simulate the erosion and penetration effects of natural rain. Laws and Parsons[44] found that the median diameter D (in millimeters) of raindrops increases more slowly than the intensity I (in inches per hour):

$$D = 2.23\ I^{0.182}$$

The median diameter divides the drops of larger and smaller diameter into groups of equal total volume. Since the distribution of diameters appears to be only slightly skewed (to larger sizes), the median is nearly the same as the mean. From the data of Laws and Parsons, the standard deviations of the diameters about the approximate mean have been found to depend, in turn, on the logarithm of the intensity:

$$s_d = 0.53 \log I$$

From these two formulas the drop sizes for rains of any intensity may be computed; for example, in rain yielding 7 inches per hour, the mean drop diameter is 3.2 mm, with a standard deviation of slightly more than 1 mm.

The speed of all of a natural raindrop through air of normal density depends only on its size, as it reaches a maximum (terminal velocity) in a distance which is quite short compared with height of the cloud within which the raindrop formed. Terminal velocities, and the distances of free fall required to attain 95 percent of this maximum speed for raindrops of various diameters, as determined photographically by Laws,(45) are:

Drop size (mm):	1	2	3	4	5	6
Term. Vel. (ft./sec):	15.9	21.6	26.4	29.1	30.3	30.5
Height of fall (ft):	7.2	16.4	23.6	25.6	24.9	23.6

The distance required to attain terminal velocity is greatest for drops about 4 mm in diameter; it decreases for larger drops, because during the early stages of their fall the larger drops tend to remain spherical and thus offer a smaller cross-section area to the passing air and attain, after short distances of fall, velocities(46) higher than consistent with their final shape. Therefore, placing nozzles at least 26 feet above the objects under test will fulfill adequately the requirements of natural speed for raindrops of all diameters.

The velocity of falling water droplets, measured by electronic methods,(47) closely approaches those given above. No measurements of distance required to attain these velocities are given but one of the investigators, Dr. Gunn, agreed that a figure of 25 to 30 feet is sufficient for all practical purposes.

The impact force of a raindrop is the result of its rate of fall and the speed of the air through which it has fallen. Wind must be simulated during the fall of the drop in order to duplicate the effect of natural impact. The strongest wind and rainfall intensities for ground and sea operated equipment, disregarding tornadoes, are encountered in hurricanes; to be completely accurate, to the speed of a hurricane wind must be added the movement of the equipment. However, to keep the requirement practical, an arbitrary wind speed of 40 mph during a portion of the rain test should prove satisfactory.

b. <u>Rainfall, Recommendations</u>

(1) <u>Operation, Ground, World-wide</u>: A 24-hour rainfall totaling 32 inches made up of the following three intensities with the indicated durations and other properties, both air and rain at 70°F:

Amount (in.):		12	2	*11	7
Duration (hr:min):		11:55	0.05	11:00	1:00
Rate (in/hr):		1	24	1	7
Drop Size (mm)	(Mean:	2.25	4.0	2.25	3.2
	(Std. Dev:	0.77	1.68	.77	1.1
Min. ht. of fall (ft):		18	26	18	25.1

*Wind speed of 40 mph during this portion of cycle.

(2) Operation, Ground, Arctic Winter: Not applicable.

(3) Operation, Ground, Moist Tropics: Same as Operation, Ground, World-wide.

(4) Operation, Ground, Hot Desert: Not applicable.

(5) Operation, Shipboard, World-wide: Same as Operation, Ground, World-wide.

(6) Short-term Storage and Transit: Same as Operation, Ground, World-wide, but applicable only to packaging; any item may be stored in an area of extreme precipitation.

c. Snow Load, Discussion

Effects of snow on military equipment are of different kinds, and the design criteria depend on the nature of the equipment.

(1) Snow affects military equipment in three basic ways:

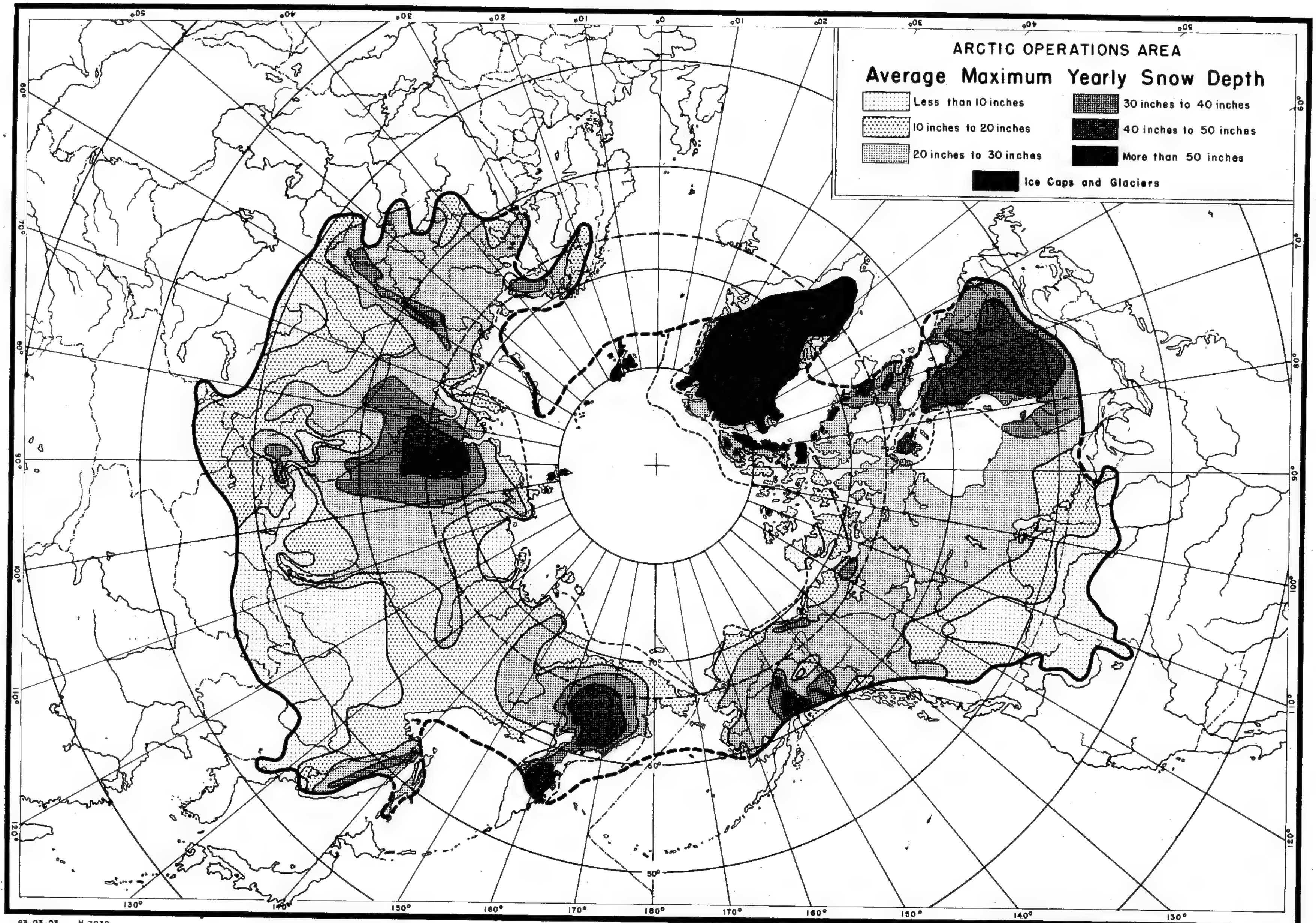
(a) By impeding movement through accumulation on the ground. This aspect, while of great importance, is beyond the scope of this report.

(b) By impeding operation of equipment through accumulation on moving parts or electrical components, such as sifting into radios, clogging air vents, and packing into recoil tracks. Since this aspect is most important when the snow is windblown, it is discussed in Section 5.

(c) By imposing a structural load on buildings, shelters, and vehicles. This aspect is examined in the following discussion.

(2) Collapse of a structure through inability to withstand the load imposed by accumulated snow may cause damage to equipment and injury to men, but choice of design criteria for shelters to eliminate this contingency is very difficult. Decisions must be made as to the degree of risk to be assumed, since any increase in the bearing strength of a shelter increases its weight and cost, thereby decreasing its portability and utility.

Greatest falls of snow (potential snowload) are encountered when temperatures are just below freezing. Areas of maximum snowload potential (deepest snow) generally occur inside but often close to the boundary of what has been termed the Arctic Operations Area (Fig. 6), defined as the area within which temperatures lower than -40°F have been observed. In Korea, for example, the maximum snow depth occurs on both sides of this boundary. Extremely heavy individual snowstorms generally occur even farther south in warmer air where more moisture is available. Such snowfalls are usually followed by melting, and even in years when such heavy snows to fall, amounts on the ground at any one time are not as great and do not accumulate to the depths that may be observed at places farther north.


ARCTIC OPERATIONS AREA
Average Maximum Yearly Snow Depth
Less than 10 inches
10 inches to 20 inches
20 inches to 30 inches
30 inches to 40 inches
40 inches to 50 inches
More than 50 inches
Ice Caps and Glaciers
83-03-03
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ENVIRONMENTAL PROTECTION SECTION MILITARY PLANNING DIVISION OQMG

Fig. 6

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Snowload depends on the density as well as the depth of deposit. Falling and freshly-fallen snow can vary widely in density, but where the amount is sufficient to be important in snowload design, the density is very close to 0.1.

The recognized world extreme[10] snowfall of 884 inches occurred at Tamarack, Calif., in the winter of 1906-07; the average yearly snowfall at Tamarack is 449 inches. These are the sums of individual snowfalls, not the depth on the ground at any one time. If there were no loss by run-off or sublimation, the equivalent water content of 43.25 inches for the snowfall months[48] indicates a snowload of about 230 lbs/ft^2. Heavier snowloads are indicated at Paradise Inn[49] 5,550 feet above sea level on the slope of Mt. Rainier, Wash., where snow averages 591 inches annually and accumulates to depths of 12 ft., highly compacted. The average density for this extremely compacted snow is 0.5, resulting in a snowload of almost 800 lbs/ft^2.

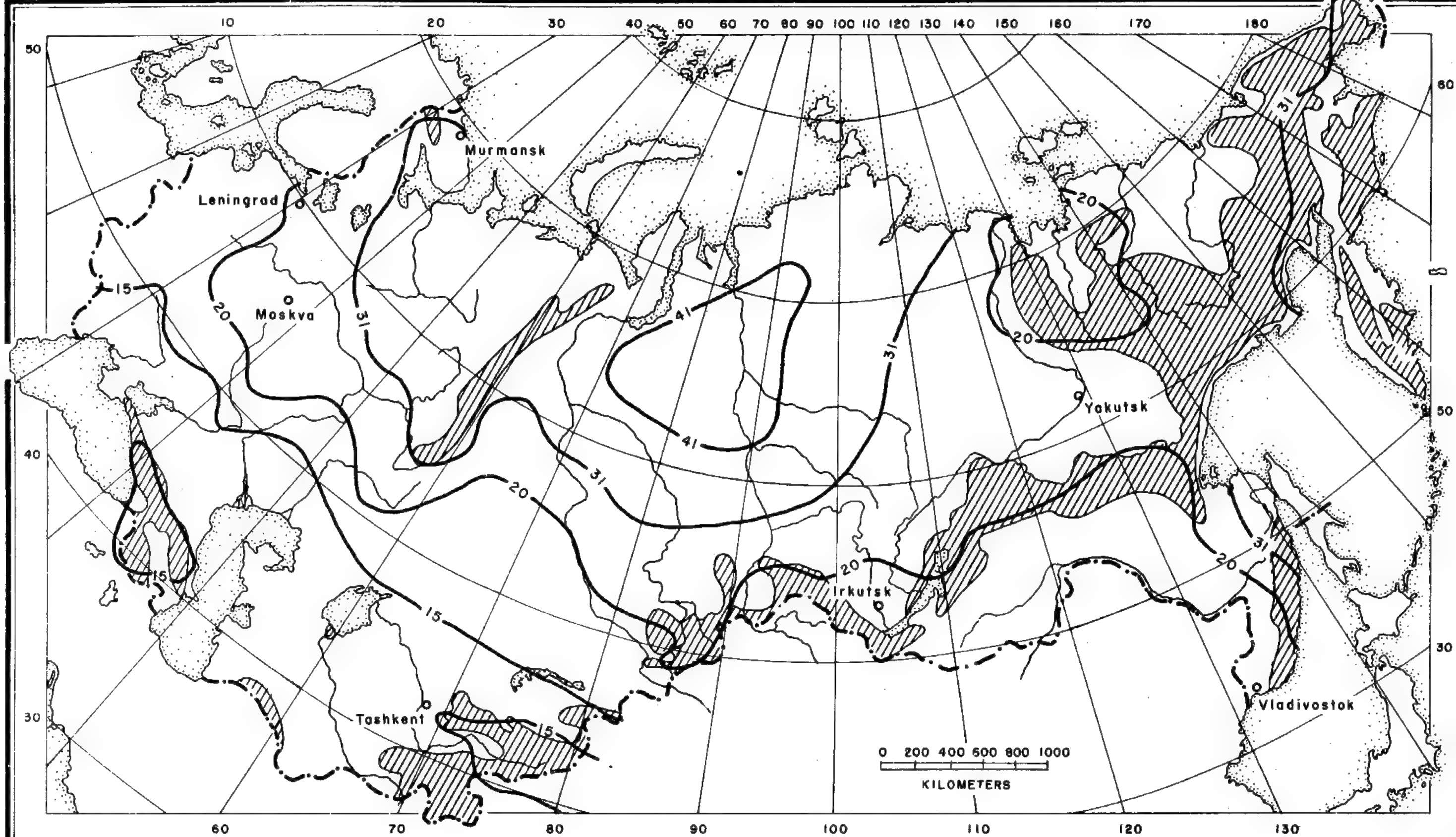
(3) Shelters and similar military combat equipment cannot be built to withstand the heaviest known snowfalls without becoming completely immobile. Therefore, snowload design criteria are proposed for four types of equipment:

Permanently installed equipment is that built and designed individually for a specific location, for example, a warehouse in an extremely snowy mountain area. Snowload criteria must be determined by the architect based upon the maximum snowload ever observed or expected in that location.

Semi-permanently installed equipment, demountable and mobile, on which snow can collect, may be located any place in the temperate or Arctic regions. This would include, for example, the large insulated-paneled, rigid, flat-roofed shelters designed for the use of troops in the Arctic. On such equipment, snow usually is not removed between snowfalls. The snowload criteria should be based upon one winter's snow accumulation, taking a calculated risk of not more than 10 percent and excepting "freak" mountain exposures.

Temporary equipment, usually large, on which snow can collect, mainly shelters such as a portable hangar, can be cleared of snow between storms. This class of equipment will not sag appreciably due to the snow loading but will collapse when its limits are reached. The snow load criteria should be based upon the maximum snow weight expected in any one storm.

Portable equipment, usually small, such as tentage, may be moved daily. This equipment generally will shed snow, but in instances where it does not, distortion will be noticeable and daily clearing mandatory. The design criteria for such equipment shall be determined on the expected maximum 24-hour snowfall.



SNOW WEIGHTS (POUNDS PER SQUARE FOOT) USED BY RUSSIAN ARCHITECTS

Mountainous Areas in which snow weights may differ from those indicated

ADOPTED (WITH UNITS CONVERTED) FROM THE ARCHITECTS ANNUAL (YEZHEGODNIK ARKHITEKTORA), PUBLISHING HOUSE OF THE ACADEMY OF ARCHITECTURE OF THE U.S.S.R., MOSCOW, 1947

Prepared by Environmental Protection Section, Research & Development Branch, Military Planning Division, O.Q.M.G. 3 October 1950

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Fig. 7

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(4) For each of these four classes, different criteria are suggested:

Permanently installed design criteria will not be discussed further except to point out that the maximum annual precipitation expected in any single year in a century can vary from about 1-1/2 to 2 times the long-term average, according to a statistical study(50) for 3 cities in north-central United States. The total snow depth that will be exceeded only 1 year in a century probably is similarly related to the average annual fall and may prove a good starting point for architects.

Semi-permanently installed design criteria can be best derived from an examination of the weight of the snow that may accumulate during a season in the centers indicated in Figure 6. In North America these areas are located in Quebec and Alaska. Pertinent weather data for months during which snow falls and accumulates without melting for three typical stations in these areas are given in Table V.

TABLE V: SNOWFALL AT THREE PLACES IN NORTH AMERICA

	NOV	DEC	JAN	FEB	MAR	SEASON		
AVIDO (48°N, 71°W)								
Temperature (°F) :		11	3	5	19	9.5	Ann. Snowfall:	116 in.
Snowfall (inches) :		22	26	17	21	86	Ann. Precip:	39 in.
Water Content (in) :		2.2	2.8	1.8	2.6	9.4	Tot. Snow Ld:	55 lbs/ft^2
MANOUAN (51°N, 71°W)								
Temperature (°F) :		11	3	5	19	9.5	Ann. Snowfall:	119 in.
Snowfall (inches) :		22	26	17	21	86	Ann. Precip:	30 in.
Water Content (in) :		2.2	2.8	1.8	2.6	9.4	Tot. Snow Ld:	51 lbs/ft^2
TALKETTA (62°N, 150°W)								
Temperature (°F) :	20	10	8	17	21	15.2	Ann. Snowfall:	130 in.
Snowfall (inches) :	16	22	23	25	27	113	Ann. Precip:	30 in.
Water Content (in) :	1.7	1.7	1.7	1.9	1.9	8.9	Tot. Snow Ld:	48 lbs/ft^2

This table indicates an average weight of snow on the ground of about 50 lbs/ft^2. Density of newly-fallen snow, computed by dividing the seasonal water content by the seasonal snowfall, is about 0.1 for each of the three stations. Since the average maximum depth of snow on the ground (40 to 50 inches, according to Fig. 6) is less than half the total snowfall, the snow on the ground compacts to a density of about 0.2.

These averages of snowfall and snow depth may be exceeded considerably in any one year. For example, at three cities in north-central United States, in 10 years per century (50) the annual precipitation exceeds the average by 1.2 to 1.4 times. Because snowfall and precipitation are interrelated, this same relationship probably can be applied

to seasonal snowfall in order to arrive at an approximation of a 10 percent calculated risk, and the snow load criterion should be modified to about 65 lbs/ft^2.

This, however, is snow on the ground; military equipment usually will be exposed at a level above the ground so that some snow will be removed by wind. In the absence of any measurements of this factor, it is estimated that about 60 percent of the seasonal snowfall collects on an elevated surface, giving a design criterion of 40 lbs/ft^2. This value is in close agreement with that used by the Russian architects for places with similar average maximum annual snow depths (Fig. 7). It is also in agreement with the specifications for 16-foot, 24-foot, and 32-foot span Hutting (normal climate), as reported in the minutes of the Fourth Meeting, on 11 January 1950, of the United Kingdom's JNSC Sub-Committee on Standardization of Service Building Construction Components:

> "For midrange of 'Normal' temperatures the huts are to be designed to support safely their self-weight and superimposed loading due to...a snow load of 10 lbs/sq ft measured in Plan. For low temperature conditions (i.e., about 5°F and below) an increased snow loading may be expected up to a maximum of 40 lbs/sq ft. This may be countered by the introduction of suitable stability members."

These considerations indicate possible overdesign in the Corps of Engineers developmental Arctic shelter (4' x 8' sections) whose design requirement is 50 lbs/ft^2.

<u>Temporary</u> design criteria must be based upon maximum weight of snow that can be expected to fall in one storm, which may be considered arbitrarily to last three days. The proper calculated risk must be used in order to provide a reasonable quantity for viewpoints of safety and economy.

As previously indicated, the heaviest single snowfalls occur in temperate areas; the United States is representative of the areas where these storms are heaviest. In the United States, the heaviest storms which have occurred at places with average annual snowfalls of only about 20 inches are just as severe as those at places with average annual amounts of 100 inches.

The most famous snowstorm in the United States,[51] one that should be considered in selection of a design limit, was the 3-day (11-14 March) "Blizzard of '88" when Troy had 55 inches (no record of water content) and Middletown, Conn., had 50 inches with water content of 5.78 inches, or a load of 31 lbs/ft^2.

Another severe storm occurred in the Sierra Nevada[52] in February 1938: "It snowed practically steadily for 18 days at an average rate of 12 inches per day (208.5 in. = 17.4 ft., total = 15.9 in. melted). February 3 and 11 had the heaviest falls (32 in. total = 2.60 in. melted and 34 in. total = 2.88 in. melted)." The total snow load of 85 lbs/ft^2 could have been removed several times during the 18 days.

For four other significant snowfalls,[10] the exact equivalent water content is not known.

Giant Forest, Calif.,	60 inches in 1 day
Angola, New York,	42 inches in 2 days (21 inch/day)
Dallas, Oregon,	54 inches in 3 days (18 inch/day)
Vanceboro, Maine,	96 inches in 4 days (24 inch/day)

Except for the first case, at a mountain station above 5,000 ft, the daily rates of fall are not very different from the 18 inches per day of the "Blizzard of '88" at Troy.

Of 129 regular Weather Bureau Stations (large cities), 3 have observed snowfalls from a single storm of more than 40 inches, 13 of more than 30 inches, and 43 of more than 20 inches. Pending complete statistical analysis of these data, an interim criterion of 40 inches per storm is recommended, giving a snowload of 20 lbs/ft^2. This value is lower than the design factor of 30 lbs/ft^2 for a non-rigid Air Force fighter shelter (which completely houses a fighter aircraft).

Portable items must meet the probable maximum snowfall of a single day. Any one winter has one chance in ten (probability 0.10) of experiencing the heaviest snowfall likely in ten years; during a three-year period, the worst snowfall in 29 years has a similar 0.10 probability of occurrence.[62]

Of 176 U. S. stations, 31 have had snowfalls exceeding 20 inches in 24 hours and 4 have recorded 30 inches in a day.[43] At each of 14 places at which maximum 24-hour snowfalls exceed 24 inches (data could not be obtained for 17 other stations with similar record snowfalls), statistical analysis of the heaviest 24-hour snowfalls in each of 50 years shows that 24-hour falls exceeding 20 inches are likely to occur, on the average, only once in about 30 years.

This value of 20 inches of snowfall in 24 hours is therefore the amount which has a 10 percent probability of occurring in any 3-year period; portable items designed for such a snowfall run a calculated risk of only 10 percent of failure due to a greater 24-hour snowfall. At the average density for newly-fallen snow of 0.1, this amounts to a load of about 10 pounds per square foot, which, consequently, is recommended as the design criterion for portable equipment.

d. Snow Load, Recommendations

Designs and tests for snow load are applicable only to equipment upon which snow can accumulate. Equipment which has no horizontal surfaces, and whose sloping surfaces are greater than the angle of repose of snow so that snow cannot accumulate on them, need not be designed to support any snow load. Furthermore, non-horizontal surfaces whose slope is less than the angle of repose need support only as much snow as can accumulate on such a slope.

(1) Operation, Ground, World-wide: For the four classes of equipment defined in par. 3 c (3) above:

Permanent	:	Not applicable
Semi-permanent	:	40 lbs/ft^2 at 0.2 density
Temporary	:	20 lbs/ft^2 at 0.1 density
Portable	:	10 lbs/ft^2 at 0.1 density

(2) Operation, Ground, Arctic Winter: Same as Operation, Ground, World-wide.

(3) Operation, Ground, Moist Tropics: Not applicable.

(4) Operation, Ground, Hot Desert: Not applicable.

(5) Operation, Shipboard, World-wide: Not applicable.

(6) Short-term Storage and Transit: Not applicable.

4. Extreme Wind Stress

a. Discussion

Wind is a most difficult meteorological element to analyze, not only because of its great variability in time and space, but because it is a vector, changing in both speed and direction. Equipment must be designed against wind stress from any direction. In addition, because the force exerted by wind varies as the square of the wind speed (and the energy of the wind, its work-doing ability, as the cube of the speed), great care must be used in choosing wind speeds as design criteria; too low a criterion may lead to destruction of equipment, too high a criterion to extremely costly overdesign.

(1) Wind speed generally increases with height, according to a logarithmic law, the rate of increase depending on the general weather conditions.[53] At times when winds are strongest, the speeds at various levels bear the following ratio to that at 10 feet:

Height in feet :	2	5	10	15	25	50	75	100
Ratio to 10-ft. wind:	0.71	0.89	1.00	1.07	1.13	1.24	1.29	1.32

In developing criteria for the design of military equipment, winds will be referred to the 10-foot level. For equipment which may be used at markedly different elevations, such as a two-man tent which is about 43 inches high or a radar antenna to be mounted atop a tall mast, the criteria developed here should be adjusted according to the above ratios.

The formula from which these ratios are obtained assumes that the wind speed at any height, under gusty conditions, is proportional to the square root of the logarithm of the height. Since wind force is proportional to the square of the wind speed, the force exerted by a strong wind increases as the logarithm of the height above the ground. Consequently, the wind stress, averaged over the entire height of an object, is somewhat greater than the stress at a point half-way up the object, but is considerably less than the stress at the highest point: a tent whose ridge-pole is 10 feet above the ground need not withstand the expected 10-foot wind.

(2) Wind speeds are measured either by the speed of rotation of a cup anemometer, or by their pressure effects as indicated by a pitot tube or bridled cup anemometer. The great majority of wind observations use cup anemometers which indicate the passage of wind (in miles or kilometers); speeds are computed by dividing the passage by the time interval.

In the United States, the following wind speeds are computed at weather stations where wind passage is recorded on a clock-driven drum:

Hourly wind speed -- total passage in one hour
Maximum wind speed -- greatest speed over a 5-minute interval
Extreme wind speed -- speed of fastest mile of wind
Highest wind gust -- Maximum instantaneous speed (taken from pitot tube anemometer).

The hourly wind speed is averaged to give daily, monthly, and annual figures. While the maximum and extreme speeds are reported regularly from many stations, and gusts from the few stations equipped to measure them, very little study has been devoted to the relationships of these various speeds. Two studies(54,55) of the records for Washington, D. C., where cup and pitot tube anemometers operate side-by-side, indicate that, at speeds above 30 mph:

Gusts are about 1.4 times the extreme speed (fastest mile).
Gusts are about 1.5 times the maximum speed (5-minute).

These approximations apparently are borne out in the more detailed data from a later investigation,(56) from which it appears also that:

Extreme speeds (fastest mile) are about 1.09 times the maximum speeds (5-minute).

In designing equipment to withstand extreme wind stress, both the instantaneous gusts and the sustained strong speeds are important.

The impact of a severe gust imposes a greater load on a structure already strained by a strong steady wind than when the general wind is lighter. Because the available wind data are for maximum and extreme speeds, rather than gusts, it seems that design criteria should be based on the strongest 5-minute wind to be expected, accompanied by gusts which exceed that speed by 50 percent.

(3) Accurate estimates of the "strongest wind to be expected" can be made only by the use of the recently-developed statistical theory of extreme values,[57] which has been applied extensively to river flood problems,[58,59] has been found useful for temperature and rainfall,[60] and has been used by the NACA[61] to determine gust loads and gust velocities for aircraft wing design. Its use requires a tabulation of the maximum wind speed in each year for 25 or more years.

According to this statistical theory, the "strongest wind to be expected" increases according to the logarithm of the time involved. Therefore, the permanency of installation of a piece of equipment must be considered in determining the extreme wind stress for which it should be designed. For example, a recent study[62] indicates that at several places in the United States the strongest wind to be expected in 25 years is about 50 percent stronger than that to be expected in 2 years.

As was done for snow load in the preceding section, four classes of equipment may be recognized. For each, the design criterion should be the strongest wind whose probability of occurring or being exceeded during the desired life expectancy is only 10 percent; i.e., the speed having an average return period of 9.29 times the life expectancy.[62]

Permanent :	Expectancy 100 years.	Return period 929 years.
Semi-permanent:	Expectancy 25 years.	Return period 232 years.
Temporary :	Expectancy 5 years.	Return period 46 years.
Portable :	Expectancy 2 years.	Return period 18 years.

b. Data

Determination of the appropriate wind speeds for each of the four classes previously defined would be simple if information were readily available on the frequencies of strong winds for various parts of the world. No studies of this kind have been found for any extensive land area of the world, although some information is available[16] concerning the frequencies of winds of various speeds over the oceans. Average wind speed data are available, for the United States[63] and the world,[64] but without any regard to the heights of the anemometers on which they are based. No definite relation is known between average wind speeds and the strongest winds that may be expected. Consequently, the available information on average wind speeds, and on observed frequencies of strong winds, must be examined for various parts of the world.

(1) Operation, Ground, World-wide: The weather station at the top of Mt. Washington, N. H., is the world's windiest observatory.[65] Other limited areas, possibly the mountain peaks of Japan, Alaska, and the Himalayas, may be windier, but observations to prove it are lacking. On 12 April 1934, a wind speed reported as 231 mph, later corrected to 225 mph after calibration, was registered twice on Mt. Washington. Because of reduced air density, the force of this wind was equal to that of a 180-mph wind at sea level. Winds of 100 mph or greater are expected 8 times a month in winter at Mt. Washington (elevation 6,288 ft.).

This world's record wind, observed during the passage of an intense temperate latitude cyclone, is far below the winds estimated for the most destructive of all storms, the tornado. The average tornado path is only a few hundred feet wide and 13 miles long[66] and tornado occurrence is limited to only part of the United States, centered in Kansas and Iowa.[67] Consequently, tornadoes should not be considered as a design factor for combat equipment, much of which cannot be made to withstand winds of 300 mph and remain mobile.

Except for tornadoes, the strongest winds at normal elevations are associated with tropical storms, i.e., hurricanes and typhoons; they are strongest on the open ocean, small islands, and along coastal areas. The Mt. Washington record wind of 231 mph was accompanied by much lower speeds at sea level, even over the open ocean, because of the distribution of upper air temperature in this type of storm.

Gusts in the most violent tropical storms are estimated[65] to reach 250 mph. Maximum winds in these tropical storms are not always attained in the tropics; as these storms mature they move into temperate latitudes. The maximum wind speed in 45 years at San Juan, Puerto Rico, (observed during a hurricane in September 1928) is 160 mph; at Blue Hill Observatory in Milton, Mass., the 1938 New England hurricane caused a wind of 183 mph, exceeding all other known wind measurements in hurricanes.

In middle latitudes, strong winds are much more frequent than in the tropics. Of 149 stations in the pre-war Japanese Empire for which data are available[68] on the strongest winds in 30 years, 79 (53 percent) experienced winds of 60 mph, 23 (15 percent) winds of 80 mph, and 6 (4 percent) winds of 100 mph; the maximum recorded speed was 163 mph. The strongest gust ever recorded in the British Isles[15] is 111 mph at Scilly, and the fastest hourly run of wind observed was 78 miles at Fleetwood. In the Aleutians, Amchitka Island experienced[69] winds of Beaufort 9 (greater than 55 mph) ten times during January and February; 110 mph was experienced[70] during the winter of 1946-47 at Adak, where 100 mph winds may be expected at least once a winter.

In the United States, of 213 U. S. Weather Bureau Stations[71] with long records, 129 (60 percent) have experienced winds stronger than 59 mph, 41 (19 percent) more than 79 mph, but only 4 (2 percent) have experienced winds greater than 99 mph. At three of these four, Brownsville, Tex.,

Cape Henry, Va., and Pensacola, Fla., these 100-mph winds presumably were associated with hurricanes, while at the fourth, North Head, Wash., the record wind probably was caused by a vicious North Pacific storm. These figures are taken from records of 25 to 73 years, from anemometers 30 to 450 feet above the ground.

Based on this survey, four stations in the northern United States were selected for detailed statistical study. Tabulation of the maximum (5-minute) wind in each month from 1912 to 1948 (all values were corrected to true speeds) yielded the strongest wind for each year; analysis, according to the statistical theory of extreme values, shows the strongest wind not likely to be exceeded in any period, and reduction of these speeds from the anemometer height to the standard 10-foot level permits intercomparison (Table VI).

TABLE VI: MAXIMUM WIND SPEED (MPH, 5-MINUTE) PROBABLE IN GIVEN NUMBER OF YEARS, AT ORIGINAL AND STANDARD HEIGHTS

	Height (feet)	Years 18	46	232	929
Tatoosh Island, Wash.	60	78	83	92	101
	10	63	67	75	82
North Head, Wash.	55	83	89	99	109
	10	67	72	80	88
Duluth, Minn.	47	61	66	73	78
	10	50	54	60	64
Burlington, Vt.	50	51	55	59	64
	10	41	45	48	52

(2) Operation, Ground, Arctic Winter: For extreme cold areas, a rough rule is that the strongest wind to be expected at temperatures below 0°F is 80 mph at 0°F, decreasing 1 mph for each 1 F° decrease in temperature. A test of this rule for Alaska and Canada indicated[72] a maximum speed at -51°F of 65 mph, and at -65°F, calm. Of the Weather Bureau Stations in Alaska,[71] Nome has experienced a maximum wind of 59 mph and Fairbanks 47 mph. In Canada, Ft. Churchill, noted for windiness, has had 78 mph in December, but no more than 58 mph in any other month.

In the Russian Coastal Arctic,[73,74] of 10 weather observatories maintaining records of wind speed, one, Malye Karmakuly (78°22'N, 52°43'E) on Nova Zemlya, has registered a speed of 129 mph. Here and on other islands in the western Russian Arctic, wind speeds greater than 45 mph occur on about 40 days a year, Dickson Island having recorded such winds on 81 days during 1917. The strongest wind in 20,000 observations on the open sea was 62 mph, but all these observations were made during the navigation season, when cyclonic activity is weakest.

At Verkhoyansk, Siberia, where the world's coldest surface air temperature was observed, the strongest wind in 10 winters(23) was 45 mph, and occurred at -10°F. On 66 of the 68 times that temperatures were below -75°F, the wind was Beaufort 0 or 1 (0 to 3 mph), and only Beaufort 2 (4 to 7 mph) on the other two.

Among the windiest areas of the world are the sea coasts around the ice-covered plateaus, especially Greenland and Antarctica, where drainage (katabatic) winds attain terrific force during cyclonic storms. The windiest fjords of Greenland are naturally avoided by both natives and explorers, so that there are no records of the strongest winds, but casual observation indicates that sustained speeds of over 100 mph are common. The dubious distinction of "The Home of the Blizzard" was claimed by Sir Douglas Mawson for his 1911-13 camp near Cape Denison, Commonwealth Bay, on the Antarctic Coast due south of Tasmania. There(75) the average wind for 22 months was 43 mph; a 12-hour average of 89 mph, maximum 96 mph, was recorded in July 1913, and a 24-hour average of 81 mph, maximum over 100 mph, in August 1913. This camp was at the mouth of a broad glacier along which air was funneled into passing cyclones from a large area of the interior plateau.

Similar situations occur elsewhere around the Antarctic coast, but in other places winds are not so violent: at Little America,(76) where the broad, level Ross Ice Shelf ends in the Ross Sea, the strongest wind measured in three full years was only 62 mph, and the yearly average speed of 11 mph is low. Strong Antarctic winds usually are accompanied by rising temperatures, readings often being over 0°F; at Little America, no wind greater than 25 mph was observed at temperatures colder than -50°F.

(3) Operation, Ground, Moist Tropics: In the moist tropics, wind speeds greater than 60 mph occur only under the direct influence of tropical cyclones; then they often exceed 100 mph. However, the frequency of tropical cyclones in any single area is extremely low compared to the number of violent extra-tropical cyclones and associated squall lines encountered in temperate areas.

The numerous thunderstorms in the tropics are seldom accompanied by the sort of violent surface winds experienced in temperate latitude thunderstorms. During 45 years at San Juan, Puerto Rico, the strongest wind for a 5-minute period during non-hurricane months is 43 mph, in January the maximum gust could hardly have exceeded 65 mph. At San Juan the winter months (non-hurricane) are windiest, with speeds of 33 mph or more occurring about 2 days per January as compared to 0.5, 0.5, and 0.8 days in hurricane months of July, August, and September.

In the Panama Canal Zone, the maximum winds recorded at the three major weather stations during 8 to 12 years were 48, 40, and 38 mph. One of these stations observed winds stronger than 25 mph only 3.3 times per year, and another 1.8 times.

At five observatories[77] from Port of Spain, Trinidad, south to Para, Brazil, winds of 25 mph were exceeded only 8 times annually at one station, 3 times at two and less than 1 at the remaining two stations. At five other stations along the north coast of South America, the strongest wind[78] recorded is 60 mph at Maracaibo, Venezuela, probably during passage of a tropical cyclone to the north. Curacao, an island off the north coast with a windier exposure, reported no wind stronger than 40 mph during 5 years.

Wind speeds in the tropical Pacific do not differ markedly from those in the tropical Atlantic, although they may be slightly stronger. Honolulu has had an extreme speed of 62 mph during a 39-year period[71] with a sustained 5-minute maximum of only 44 mph. Many equatorial islands, such as Baker and Howland, show maximum winds[79] of only 15 to 25 mph. Winds at Nauru[79] rarely exceed force 5 (24 mph). However, the Gilbert Islands, also close to the equator, experience occasional gales (39 to 46 mph), as do the more southerly Fiji Islands[79] where the trade winds "occasionally strengthen to moderate gales." At four stations in the Philippines, a typhoon area, where two observations were made daily for four or five years, maximum wind speeds were 28, 22, 22, and 16 mph. In 41 years at Manila, one-hour average winds of 62 mph were twice experienced during typhoons; peak gusts during such winds probably were well over 100 mph. Winds of gale force or greater (over 39 mph) are expected only 3.3 times annually at Manila.

(4) <u>Operation, Ground, Hot Desert</u>: The rather meagre data on wind speeds in hot (tropic and sub-tropical) deserts indicate generally light to moderate speeds. This lack of extremely strong winds is due to lack of energy: the energy of the extreme winds in tropical and extra-tropical storms is derived from the release of latent heat in the condensation of water vapor. In most deserts, of course, there is a scarcity of water vapor. However, moderately strong winds are quite frequent in some deserts. The Quartermaster Corps expedition to Death Valley in the summer of 1950 observed winds greater than 40 mph at only 12 feet above the ground on 14 percent of the days.[8]

Along the edges of deserts, such as in southwestern United States (Texas, New Mexico) violent storms occur when hot, dry desert air overlies cooler, moist tropical air, creating an extremely unstable situation if the air is lifted by normal weather processes. The resulting turbulent thunderstorms and tornadoes in such cases, however, occur in the bordering moist tropics or temperate areas rather than in true deserts. The similar and notoriously violent West African squalls (often called tornadoes, erroneously) are associated with the boundary between the dry air of the Sahara and the moist air of the equatorial jungle or coasts.

Dust devils, a dry counterpart of the tornado, lack the violence of the tornado as they are not energized by the latent heat of condensation. The strongest wind observed in dust devils during one study in the Mojave Desert[80] was 21 mph in the largest devil studied, 200 feet

in diameter; winds as high as 40 mph in dust devils in the Sahara[81] are reported, and one with a speed estimated that high was observed by the Quartermaster Corps Death Valley expedition in 1950.[8]

Near the Red Sea, "Hoboobs", "Masses of dust and sand several thousand feet high on a front 10 to 20 miles in width sweep along at a speed of 30 mph."[82] Gusts as high as 60 mph occur[81] in the most intense North African "Hoboobs", whose entire duration is about three hours. At Ft. Lamy, French Equatorial Africa, the wind was estimated at 93 mph for about ten minutes in an extremely intense storm, which probably formed along the boundary between Sahara desert air and moist equatorial air.

At Yuma, Ariz., one of the few stations in desert regions of the United States maintaining continuous records of wind speeds, the extreme gust[71] recorded in 67 years was 45 mph, atop a 40-foot tower in an irrigated valley. At Phoenix, Ariz., and Salt Lake City, Utah, semi-desert stations, the extreme gusts were 65 mph in 48 years and 63 in 70 years, respectively, at 82 feet and 46 feet above the ground.

(5) Operation, Shipboard, World-wide: Over the open ocean, there is less friction between the air and the sea surface than between air and land. Consequently, storms of equal intensity cause stronger winds over water than over land. In addition, many storms originate and develop over the ocean, especially tropical cyclones (hurricanes and typhoons).

Winds to be expected at sea therefore are stronger than those discussed for land areas. The original Navy suggestions (Table I) were 50 knots at -35°F and 90 knots at 150°F. More recent design criteria for Arctic and cold weather areas[27] incorporate wind speeds of 100 knots (115 mph) at 80°F and 40 knots (47 mph) at -20°F. Since shipboard equipment generally is subject to world-wide usage, the stronger wind (100 knots) should be taken as the design criterion.

The rate of increase of wind speed with altitude over water, in the absence of any definite studies, may be assumed to be the same as that over land. No height for the 100-knot wind was indicated in the Navy criteria, but it probably is well above the surface. For a 100-knot wind at 100 feet, the speed would be 75 knots at 10 feet.

Because friction over water is less than that over land, it is probable that gusts do not exceed average maximum speeds by as large a factor as the 1.5 value estimated for land conditions. If a ratio of 1.3 is assumed between peak gusts and maximum 5-minute wind, gusts corresponding to these speeds would be 130 knots at 100 feet and 100 knots at 10 feet.

(6) Short-term Storage and Transit, World-wide: Properly packaged items should not be susceptible to wind damage, so that extreme wind stress is not applicable, except to the packaging.

c. Conclusions

The preceding discussion indicates that high winds are more prevalent as a whole in temperate areas than in the Arctic Winter, Moist Tropics, or Hot Desert, but that limited areas within each of these climatic zones may be endangered infrequently by winds equally as strong. Consequently, no further differentiation need be attempted under Operation, Ground; World-wide limits should be applied also to Arctic Winter, Moist Tropics and Hot Desert.

However, the windiest temperate places are those on mountains and along coasts and on islands. At most places, the frequency of very strong winds is not as high as it is in these places of exceptional winds. While the total area of places experiencing such exceptional winds is rather small, many of them are of considerable military importance (Aleutians, Newfoundland).

To avoid costly overdesign of military equipment, most of which will operate in areas of ordinary winds rather than of exceptional winds, it seems advisable to base the design criteria for Operations, Ground, World-wide on the strongest wind:

(1) 10 feet above the ground (value to be corrected for other elevations),
(2) during a 5-minute period,
(3) with allowance for gusts at 50 percent greater speed,
(4) with a 10 percent probability of occurrence in desired life expectancy depending on the type of equipment,
(5) in all but exceptionally windy areas, for which auxiliary means must be provided.

For Operation, Shipboard, World-wide, some of these qualifications do not apply, and the criteria should be those of the exceptionally windy places.

d. Recommendations

(1) Operation, Ground, World-wide: Shall have the built-in ability to withstand the following wind speeds (miles per hour), depending on class of equipment, 10 feet above the ground (speeds to be adjusted for other heights), and be capable of application of auxiliary devices to withstand the indicated higher speeds:

	BUILT-IN		AUXILIARY KITS	
	steady	gusts	steady	gusts
Portable	40	60	60	90
Temporary	50	75	70	105
Semi-permanent	65	100	80	120
Permanent	depends on individual site			

(2) Operation, Ground, Arctic, Winter: Same as World-wide.

(3) Operation, Ground, Moist Tropics: Same as World-wide.

(4) Operation, Ground, Hot Desert: Same as World-wide.

(5) Operation, Shipboard, World-wide:

	STEADY		GUSTS	
	knots	mph	knots	mph
10 feet above the water	75	85	100	115

(6) Short-term Storage and Transit: Same as Operations, Ground, World-wide, for packaging only.

5. Extreme Penetration and Abrasion

Wind-blown objects, such as snow, sand, and dust, can render poorly-designed items just as inoperative as can failure due to extremes of temperature, precipitation, humidity, or wind. Because of the difficulty of simulating natural conditions of penetration and abrasion, and the complexity of the wind-blown objects, no satisfactory set of tests for these environmental conditions has been proposed hitherto.

a. Blowing Snow, Recommendations

The principal danger of blowing snow is that it may gain access to the interior of an item and clog it up or melt and refreeze inside as solid ice. Delicate mechanical items may be damaged beyond repair: protective devices such as shelters may have pools of water formed within them, becoming hazards to personnel or creating morale problems. Blowing snow may be encountered in almost all places poleward of the tropics, in the air, or the sea, and on land, and must be considered in the design of much military equipment.

The smaller the snow crystal and the faster it is blowing, the more easily it will gain access to the interior of an item. Snow crystals may vary in size from a small fraction of a millimeter to 1-1/2 millimeters.[83] Flakes as large as 15 x 8 inches have been observed[84] at Fort Keogh, Montana. Winds that blow snow vary from the very light wind which will just pick up fresh cold snow to the extreme winds of over 100 mph during snow squalls in the Aleutians, when temperatures hover about freezing.

(1) Operation, Ground, World-wide: Crystals 1 to 3 mm. diameter blowing at 40 mph at 0°F.

(2) Operation, Ground, Arctic Winter: Same as World-wide.

(3) Operation, Ground, Moist Tropics: Not applicable.

(4) Operation, Ground, Hot Desert: Not applicable.

(5) Operation, Shipboard, World-wide: Same as Operation, Ground, World-wide.

(6) Short-term Storage and Transit: Same as Operation, Ground, World-wide, but applicable only to packaging.

b. Blowing Sand, Recommendations

Blowing sand is usually encountered in hot deserts, but may be found on sandy beaches and in dry continental interiors. The major destruction caused by blowing sand is that of abrasion; in addition, machinery may be clogged by sand forced through small crevices by strong winds. In deserts, the reduction of insolation by blown sand and general mixing of the air prevent air temperatures from exceeding 110°F during sand storms.[85]

Several studies have been made of blowing sand; Bagnold[86] gives the diameter of sand particles in general as 0.01 to 1.0 mm. and that of the average desert sand (mostly quartz) as 0.18 to 0.30 mm; these will pass through a 50-mesh screen but not an 80-mesh. The threshold wind speed necessary to raise sand of 0.30 mm. grain diameter is 20 cm/sec (0.45 mph); this is actually the speed in the air film about 0.3 cm above the sand. Sand grains themselves rarely rise above 1 meter (39 in), and the average height is around 10 cm (4 in). At this level, wind speeds in the neighborhood of 5 mps (11 mph) are required to set the grains on the ground in motion. In nature, the wind at 5 ft. is three times[53] as strong as that at 10 cm, so that a 5-foot wind of 33 mph is required to blow sand.

In the original Air Force document on Environmental Testing, Specification No. 41065, the test for both sand and dust required that all particles pass through a 170-mesh screen. Such particles must be less than 0.088 mm. in diameter and, consequently, much smaller than the usual run of desert sand.

Ships near desert coasts may experience severe sand storms. Bahrein Island in the Persian Gulf averages 3 days in June with sandstorms. The HMS Cyclomen[15] encountered such a storm during which the visibility fell to less than a cable (608 ft.) with wind of force 5 to 6 (25 to 30 mph).

(1) Operation, Ground, World-wide: 0.18 to 0.30 mm. diameter sand, 40 mph at 5 ft., 100°F.

(2) Operation, Ground, Arctic Winter: None.

(3) Operation, Ground, Moist Tropics: None.

(4) Operation, Ground, Hot Desert: Same as World-wide.

(5) Operation, Shipboard, World-wide: Same as Operation, Ground, World-wide.

(6) Short-term Storage and Transit: Same as Operation, Ground, World-wide.

c. Blowing Dust, Recommendations

Dust is detrimental mainly to mechanisms such as gun controls, internal combustion engines, etc. It behaves as an abrasive when trapped between moving parts and also clogs delicate mechanisms. Dust may be found any place in the world, but it is mainly a problem in smoky industrial and dry windy areas. Special operations such as drilling and blasting also cause considerable dust.

In an excellent report,[5] "Environmental Criteria for Aircraft Design", a thorough review of sand and dust is given. Dust in general[87] ranges in size from 0.1 microns (10^{-4}mm) to 10 microns (10^{-2}mm), with the average size under normal conditions in open country about 0.5 microns (5×10^{-4}mm) consisting of particles from 0.3 to 1.7 microns (3 to 17×10^{-4}mm). Within a dense dust cloud at Washington, D. C., a dust counter[88] determined a concentration of 12,000 dust particles per cubic centimeter, with average diameters of 1.5 microns (1.5×10^{-3}mm) in one case and 0.95 microns (9.5×10^{-4}mm) in another. However, settled dust collected at the same time ranged in diameter from 1.0 to 130 microns (.001 to .13 mm).

Particles with diameters greater than 80 microns (.08 mm) are defined by Bagnold[86] as sand. A maximum of 60,000 particles per cubic centimeter have been observed with an Owens dust counter.[89] These smoke and dust particles have an average mass of about 1.0×10^{-13} grams per particle. Evidently, the dust in a good dust storm will average about 6×10^{-9} grams per cm3.

Although the wind speeds accompanying these dust storms are unknown, it is estimated from Bagnold's report that a speed of about 10 mph is required to carry the dust after it is in the air; much higher speeds carry the dust of a desert storm. Apparently, dust problems occur principally in desert sandstorms, but can also occur in industrial areas such as large cities.

(1) Operation, Ground, World-wide: 6 x 10 gr/cc of dust, .0001 to .01 mm. diameter, 15 mph at 5 ft., 70°F.

(2) Operation, Ground, Arctic Winter: Not applicable.

(3) Operation, Ground, Moist Tropics: Not applicable.

(4) Operation, Ground, Hot Desert: Same as World-wide.

(5) Operation, Shipboard, World-wide: Same as Operation, Ground, World-wide.

(6) Short-term Storage and Transit: Same as Operation, Ground, World-wide.

6. Salt Spray

a. Discussion

Salt spray is a problem for military equipment wherever it occurs, regardless of the concentration of the salt spray iteself.

Ocean salinity averages 34.6 parts per thousand[90] varying from 33.64 in the North Pacific to 36.87 in the North Atlantic. In certain arms of the sea exceptions exist: in the Gulf of Bothnia, salinity may be less than 5 parts per thousand, whereas, in the Red Sea it reaches 40. "In spite of wide variations in temperature, salinity and marine organism growth from place to place, there are surprisingly small differences in corrosion of common metals and alloys when they are exposed to corrosion by sea water at different points throughout the world."[91]

(1) In the corrosion of articles immersed in sea water, high temperatures are compensated for by the development of protective calcareous deposits and marine growth which stifle the attack of corrosion,[91] but salt spray corrosion may be accelerated[92] by raising the temperature: for a salt spray test, Blum and Waldron recommend a temperature of 95°F, only 1 F° lower than the highest water temperature[15] ever recorded by a ship under way.

Acceleration of corrosion in salt spray apparently results from the replenishment of oxygen in the film of solution adjacent to the object undergoing corrosion. If the object were immersed in a continuous bath of sea water, the oxygen in the surface film, required for corrosion, would soon be depleted and thereafter would be available only at a rate depending on diffusion through the surrounding water from the air. However, continuous settling of new particles of solution, as in actual salt spray, maintains the oxygen in the surface film at peak concentration.

As pointed out in proposed criteria for aircraft design,[5] salt spray is a corrosion factor only within the first 1000 ft. inland from water except in conditions of unusual wind. Little corrosion may be expected more than 500 feet above the surface.

(2) Difficulties inherent in exposure of test items to natural salt water or salt spray corrosion have led to the formulation of various synthetic sea waters for accelerated or aggravated tests. However, no such tests yet developed are fully reliable in predicting the performance of items exposed to natural salt water corrosion.

(a) Blum and Waldron[92] conclude that "the use of a 20 percent sodium chloride does not accelerate corrosion much above that with a 3 percent solution (e.g., sea water)." However, Mr. F. E. Cook of the Bureau of Ships has pointed out that zinc is an exception to this general rule, suffering much greater corrosion from the stronger solution.

(b) Dr. T. P. May of the International Nickel Company, recently perfected a synthetic sea water which accurately reproduces the type of corrosion caused by natural sea water on both steel and zinc, when the effects of these solutions are compared in the usual test cabinet. However, he pointed out, the corrosion thus produced is quite different from that resulting from natural marine exposure and therefore he emphatically opposed the use of these solutions for accelerated tests.

(c) Dr. A. L. Alexander of the Naval Research Laboratory studied the deterioration of paints, enamels and lacquers, caused by natural sea water, synthetic sea water and brine solutions in test cabinets. He concurred with May that these reactions are not "accelerated tests". However, they may speed up the detection of a flaw in a finish or coating.

(d) The current Federal Specification QQ-M-151a, amendment 3, for salt spray corrosion, perfected after years of experience, is the best presently available, although it is not correlated with performance of an item under actual exposure aboard ship. A suggestion by Mr. T. F. Kearns of the Bureau of Aeronautics that 100 hours of this salt spray test equals 180 days of actual exposure may be extremely misleading, Cook said, as 100 hours may give results equivalent to exposure of less than 12 days in some cases, more than 200 in others. Also, as has been already pointed out, the type of corrosion is usually quite different from that found in nature.

(3) The chief value of a salt spray test is presumed to be its ability to indicate the relative corrosion of similar materials, and to indicate the relative porosity of protective coatings. However, recent investigations find both of these concepts false:

(a) May also "exposed low and high copper steel to salt spray and in the marine atmosphere. The salt spray test does not distinguish between these similar steels (copper content, .05 and .27 percent, respectively) whereas, it has long been established that these steels differ widely in the atmosphere where the high copper steel exhibits far greater resistance to corrosion. In this case, the salt spray test is not an excellent means of comparing these steels. I expect that this could be demonstrated with other similar materials."

(b) Mr. C. H. Sample of The International Nickel Company "found that when a coating fails in the salt spray test, it usually fails to meet service requirements although the manner of failure may be quite different in the spray cabinet and in the atmosphere. On the other hand, the fact that a coating passes a salt spray test does not mean that the coating will be satisfactory in service. As an example, the usual 75-hour salt spray test for automobile bumper stock will not reveal differences between certain copper-nickel-chromium and nickel-chromium coatings. On the other hand, one year in a mild marine atmosphere will cause the copper-nickel-chromium coating to fail badly and will have only slight

effect on the chromium-nickel coatings. In this case the salt spray as commonly used does not reveal the differences in these coatings.

"Another situation exists in which salt spray tests may lead to false conclusions. Zinc and cadmium coatings frequently are considered as similar and they are frequently compared with one another. However, in the salt spray, zinc coatings invariably are worse than cadmium coatings but the reverse is true in ordinary atmospheric exposures. Accordingly, comparisons of salt spray tests of these materials will be misleading."

"It cannot be emphasized too strongly that the salt spray test can be very misleading and should not be used, even in developmental work, except where there is a long experience to use in interpretation of the test results. Without this experience, use of the salt spray test can be worse than useless."

(4) These informal comments indicate that the only true test of salt spray corrosion is actual exposure on a beach: such a site should be maintained by the military services jointly for salt spray testing. The QQ-M-151a tests, and similar tests using natural or synthetic sea water, should not be used to determine the acceptability of materials and coatings, although they may have limited use in the detection of flaws in finishes or coatings.

b. Recommendations

(1) Operation, Ground, World-wide: Natural exposure site.

(2) Operation, Ground, Arctic Winter: Not applicable.

(3) Operation, Ground, Moist Tropics: Not applicable.

(4) Operation, Ground, Hot Desert: Not applicable.

(5) Operation, Shipboard, World-wide: Natural exposure site.

(6) Short-term Storage and Transit: Natural exposure site, for packaging only.

7. Extreme Atmospheric Pressure

Atmospheric pressure variations usually have little effect on the design and consequent testing of most combat items. However, they may be critical for the operation of two classes of items: those which require oxygen in combustion, and those sealed units which might explode or collapse with pressure changes. Gasoline tent heaters, for example, must have an adjustment enabling them to operate efficiently at mountain elevations, while sealed chronometers must not leak when transported in an unpressurized cargo airplane.

a. Discussion

Standard atmospheric pressure at sea level is 1013.2 millibars, 29.92 inches of mercury, or 14.7 pounds per square inch. However, much higher pressures are found in winter polar air masses, and in summer subtropical anticyclones. No record has been found of the world's maximum station pressure (not reduced to sea level). Pressures shown on surface weather maps are artificially reduced to sea level, so that only those on the coast, over water, or near sea level are valuable in determining the extreme maximum pressure. For Washington, D. C., highest sea level pressure observed from 1873 to 1950, 77 years, was 1050.1 millibars. It is estimated that 1060 millibars, (31.30 inches of mercury or 15.4 pounds per square inch) is a fair maximum atmospheric pressure for design and testing of all equipment for which this factor is critical. Likelihood of occurrence of this pressure was not estimated because such detail is not important. (The "standard" pressure is about 1056 millibars at 1292 feet below sea level, level for the Dead Sea, the lowest place on the surface of the earth.)

The lowest atmospheric pressure under which combat items may be required to function depends primarily on altitude. However, at sea level, for sea borne equipment, it depends on cyclonic activity. The lowest atmospheric pressure ever observed aboard ship[65] is 887 millibars (26.18 inches of mercury or 12.9 pounds per square inch).

For ground operations, mountainous locations must be considered. However, such operations generally are confined to valleys, plateaus and passes, and 18,000 feet is the highest altitude at which operations can reasonably be expected. The "standard" pressure[93] corresponding to this altitude is 505 millibars (14.94 inches of mercury or 7.35 pounds per square inch). Pressure variations due to weather need not be considered because of the arbitrary choice of this elevation.

Above 5,000 feet, moist tropical and hot desert areas are no longer hot, and so no longer require special equipment. Standard pressure[93] at 5,000 feet is 844 millibars (24.85 inches of mercury or 12.2 pounds per square inch).

For short-term storage and transit an elevation of 25,000 feet in an unpressurized cabin is considered very possible with modern aircraft; this elevation is used by the Air Material Command in the "Testing of Dangerous Materials for Transportation by Air." At such an elevation "standard" pressure is 375 millibars, 11.1 inches of mercury, or 5.45 pounds per square inch.

b. Recommendations

(1) Operation, Ground, World-wide: Maximum pressure 1060 millibars, 31.30 inches of mercury, or 15.4 pounds per square inch. Minimum pressure 505 millibars, 14.94 inches of mercury, or 7.35 pounds per square inch.

(2) Operation, Ground, Arctic Winter: Same as Operation, Ground, World-wide.

(3) Operation, Ground, Moist Tropics: Maximum same as World-wide. Minimum pressure 844 millibars, 24.85 inches of mercury, or 12.2 pounds per square inch.

(4) Operation, Ground, Hot Desert: Same as Operation, Ground, Moist Tropics.

(5) Operation, Shipboard and Beach, World-wide: Maximum pressure same as Operation, Ground, World-wide. Minimum pressure 887 millibars, 26.18 inches of mercury, or 12.9 pounds per square inch.

(6) Short-term Storage and Transit: Maximum pressure same as World-wide Ground Operation. Minimum pressure 375 millibars, 11.1 inches of mercury, or 5.45 pounds per square inch.

III. CONCLUSION

In the preceding sections, environmental stresses affecting the operation of military items have been analyzed as thoroughly as available data permit, and suitable conditions have been proposed to simulate the probable and practical extreme stresses. These conditions, explained and justified in detail, are summarized in Table VII, usable as a table of design criteria, or as a basis for the design of acceptability tests.

Intermediate environmental stresses (not extremes) based upon economic considerations or physical limitations, such as the requirement[2] of "built-in" design down to -25°F with auxiliary kits permitted in the range from -25 to -65°F, are not considered.

But no matter how carefully tests based on these proposals are conducted, they can never duplicate completely the extremes of natural conditions. The final proof of the durability or operability of an item is in its actual use under the most extreme conditions for which it was designed, i.e., the probable or practical extremes as set forth in the preceding sections.

Consequently, for each of the seven environmental tests ~~have~~ proposed, suitable exposure and testing sites should be established at which the results of routine laboratory tests can be verified. Such sites[94] should be in the continental United States if possible, otherwise, in nearby territories with optimum accessibility to technologists actually designing and testing the items.

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CLIMATIC EXTREMES FOR M

(FOR USE AS BASES IN DESIGN

EXTREME STRESS CONDITIONS		ENVIRONMENTAL FACTORS	OPERA GROUND (OUTDOO WORLD - WIDE				ARCTIC WINTER	MOIST TROPIC				
THERMAL	HOT	DURATION (hours) AIR TEMPERATURE (°F) RADIATION (watts/ft²) UV <4000 Å (%) IR >7000 Å (%) WIND SPEED (mph)	10 90 0 0 0 7	5 → → 6 50 7	4 125 105 6 50 7	5 → → 6 50 7		10 75 0 0 0 4	1 → 0 0 0 4	4 → → 4.5 51 4	4 95 90 4.5 51 4	4 → → 4.5 51 4
	COLD	DURATION (hours) AIR TEMPERATURE (°F) SKY TEMPERATURE (°F) WIND SPEED (mph)	EQUILIBRIUM -40 -60 0		72 -65 -80 0		W					
HUMIDITY	WET	DURATION (hours) ABS. HUMID. (grains/ft³)	CONTINUOUS 13				CONTINUOUS 2.1	W				
		DURATION (hours) RELATIVE HUMIDITY (%) AIR TEMPERATURE (°F)	20 95 ± 2 80 to 85		4 100 w/cond 75 to 80		CONTINUOUS 98 to 100 -65	W				
	DRY	DURATION (hours) ABS. HUMID. (grains/ft³)	CONTINUOUS 0.01				W					
		DURATION (hours) RELATIVE HUMIDITY (%) AIR TEMPERATURE (°F)	10 15 90	5 → →	4 5 125	5 → →						
PRECIPITATION	RAIN	DURATION (hrs: mins.) AMOUNT (inches) DROP DIAMETER {MEAN (mm) {STD. DEV. (mm) MIN. HT. OF FALL (ft.) AIR & WATER TEMP (°F) WIND SPEED (mph)	11:55 12 2.25 0.77 18 70 0	00:05 2 4.00 1.68 26 70 0	11:00 11 2.25 0.77 18 70 40	01:00 7 3.20 1.10 25 70 0		W				
	SNOW	*EXPECTANCY (days) SNOW LOAD (lb./ft.²) DENSITY	1 10 0.1	3 20 0.1	150 40 0.2		W					
WIND	*10 ft. above Surface. Correction to other hgts. Given on page 39.*	*EXPECTANCY (years) ORDINARY {STEADY (mph) {GUSTS (mph) ΔEXCEPTIONAL {STEADY (mph) {GUSTS (mph)	2 40 60 60 90	5 50 75 70 105	25 65 100 80 120		W	W				
PENETRATION AND ABRASION	BLOWING SNOW	FLAKE DIAMETER (mm) WIND AT 5 FT. (mph) AIR TEMPERATURE (°F)	1 to 3 40 0				W					
	BLOWING SAND	GRAIN DIAMETER (mm) WIND AT 5 FT. (mph) AIR TEMPERATURE (°F)	0.18 to 0.30 40 100									
	BLOWING DUST	GRAIN DIAMETER (mm) DENSITY (grams/cm³) WIND AT 5 FT. (mph) AIR TEMPERATURE (°F)	0.0001 to 0.01 6 x 10⁻⁹ 15 70									
SALT SPRAY			NATURAL EXPOSURE					W				
PRESSURE	MAXIMUM		1,060 mb = 31.30 in. = 15.40 lb / in²				W	W				
	MINIMUM	PRESSURE HEIGHT	505 mb = 14.94 in. = 7.35 lb / in² 18,000 ft. = 5.49 km					844 mb = 24.85 in. = 12.20 lb. / 5,000 ft. = 1.52 km				

C-7241

*= Expectancies Vary with Type of Equipment

TYPE	SNOW	WIND
Portable	1 day	2 years
Temporary	3 days	5 years
Semi-permanent	150 days	25 years

W = Same as Operation, Ground, World-wide.
P = Same as Operation, Ground, World-wide for Packaging only.
→ = Change from preceding to following condition at uniform rate
Δ = Equipment for Exceptional Windy Areas requires auxiliary kit
A = Additional Dry Humidity Test of Storage: 30 days at 50°F an

:S FOR MILITARY EQUIPMENT

S BASES IN DESIGNING TESTS)

P E R A T I O N						SHORT-TERM STORAGE & TRANSIT LAND-SEA-AIR (WORLD-WIDE)
ı U N D (O U T D O O R S)					SHIPBOARD (WORLD-WIDE)	
WIDE		ARCTIC WINTER	MOIST TROPICS	HOT DESERT		
[illegible]	5 → 6 50 7		10 75 0 0 0 4 / 1 → 0 0 4 / 4 → 4.5 51 4 / 4 95 90 4.5 51 4 / 4 → 4.5 51 4 / 1 0 0 4	W	10 90 0 4.5 51 5 / 1 → 0 4.5 51 5 / 4 → 4.5 51 5 / 4 100 90 4.5 51 5 / 4 → 4.5 5.1 5 / 1 0 4.5 51 5 *Sea Surface 95°F*	10 90 0 0 0 0 / 5 → 0 0 0 0 / 4 160 0 0 0 0 / 5 → 0 0 0 0
72 -65 -80 0		W			24 -20 -45 45 = 40 knots *Sea Surface 28°F*	EQUILIBRIUM -40 0 / 24 -80 0
S		CONTINUOUS 2.1	W	W	W	
4 0 w/cond 5 to 80		CONTINUOUS 98 to 100 -65	W		W	W
S		W		CONTINUOUS 0.5	CONTINUOUS 0.17	
5	5 →			W		10 15 90 / 5 → / 4 2 160 / 5 → *see note A*
0 .5 7	01:00 7 3.20 1.10 25 70 0		W		W	P
150 40 0.2		W				
25 65 100 80 120		W	W	W	85 (75 knots) 115 (100 knots)	P
		W			W	P
50				W	W	W
01				W	W	W
SURE			W		W	P
40 lb / in²		W	W	W	W	W
35 lb / in² km			844 mb = 24.85 in. = 12.20 lb. / in.² 5,000 ft. = 1.52 km	844 mb 5,000 ft.	887 mb = 26.18 in = 12.90 lb/in² SEA LEVEL	375 mb = 11.1 in. = 5.45 lb. / in.² 25,000 ft. = 7.62 km.

Environmental Protection Section
Military Planning Division, OQMG

ıeration, Ground, World-wide.
eration, Ground, World-wide for Packaging only.
ı preceding to following condition at uniform rate during indicated duration.
'or Exceptional Windy Areas requires auxiliary kits to permit withstanding indicated winds.
ıry Humidity Test of Storage: 30 days at 50°F and 1/2% Relative Humidity (Simulating Arctic Storage).

C23743

2

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